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Economic analysis of limestone processing side stream utilisation

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Kalkkikiven jalostuksen sivuvirtojen hyödyntämisen kannattavuusanalyysi

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Tiivistelmä

Teollisuuden sivutuotteiden ja jätteiden hyödyntäminen on yhä tärkeämpää ja suuremman mielenkiinnon ja tutkimuksen kohteena. Sivutuotteisiin ja jätteisiin on sitoutunut arvoa tuotantoprosesseissa tuotantokulujen myötä, niiden hävittäminen aiheuttaa myös kustannuksia ja ne voivat olla vielä sinänsä kelvollista materiaalia uusien tuotteiden valmistamiseksi. Tekninen tutkimus ja tuotekehitys ovat tärkeää sivutuotteiden hyödyntämiseksi, mutta yhtä lailla on tärkeää tarkastella teollisuuden sivutuotteiden hyödyntämistä myös taloudellisesta näkökulmasta.

Tämän työn aiheena ovat SMA Mineralin kalkinpoltossa ja dolomiitin murskauksessa syntyvien sivutuotteiden hyödyntäminen. Työ keskittyy tarkastelemaan sivutuotteiden käyttöä kiertotalouden periaatteiden asettamassa kontekstissa ja arvioimaan hyödyntämisen kaupallista hyötyä. Työn tavoitteena on kehittää kahdesta kolmeen lupaavaa arvoketjuskenaariota tuotantoprosesseissa syntyvien alitekalsiitin, suodatinpölyn, epäkurantin poltetun kalkin ja hienojakoisen dolomiitin hyödyntämiseksi. Lisäksi valittujen skenaarioiden business caset esitetään ja analysoidaan alustavan taloudellisen hyödyn arvioimiseksi.

Työssä käytetään pääasiassa kvalitatiivisia ja deskriptiivisiä tutkimusmenetelmiä. Suurin osa työstä perustuu järjestettyyn innovaatiotyöpajaan, jossa valittiin arvoketjuskenaariot analysoitavaksi. Lisäksi haastatteluita käytettiin työpajan täydentämiseksi. Lisäksi käytettiin business case analyysia skenaarioiden taloudellisen hyödyn arvioimiseksi. Teoreettinen pohja rakennettiin perusteellisella kirjallisuuskatsauksella, jossa käsiteltiin keskeisiä teemoja teollisuuden sivuvirtojen taloudelliseen analysointiin.

Työn tärkeimpänä tuloksena oli kolme arvoketjuskenaariota; reaktiivinen pintarakenne, vesistöjen kalkitus ja sivutuotteiden agglomerointi (rakeistaminen ja briketöinti). Kaupallisen hyödyn puolesta kiinnostavimpia olivat rakeistus ja briketöinti, joiden taloudellinen hyöty (tuotto + säästyneet jätekulut) olivat suurimmat. Tekniseltä kannalta tarkasteltuna pintarakenne ja vesistöjen kalkitus olivat myös toimivia ratkaisuja ja kannattavia läjitykseen verrattuna.

Työn tulokset toimivat pohjana seuraaville askeleille SMA Mineralin materiaalitehokkuuden parantamisessa. Niiden avulla voidaan valita mahdollisia jatkotutkimuksen kohteita skenaarioiden jatkokehittämiseksi tai tarkempien lisätietojen saamiseksi.

Työn tulokset ovat varsin spesifisiä työn kontekstille. Valitut skenaariot vaihtelevat esimerkiksi yrityksen sijainnin ja tavoitteiden mukaan. Lisäksi työ on aikasidonnainen ja tulokset voivat olla hyvin irrelevantteja esimerkiksi kymmenen vuoden päästä. Skenaarioiden valitsemiseen ja analysointiin käytetyt menetelmät soveltuvat kuitenkin muidenkin alojen sivuvirtojen hyödyntämisen analysointiin.

Avainsanat: sivuvirrat, sivutuotteet, jätteet, kiertotalous, liiketoiminnan ekosysteemi, liiketoimintamalli, arvoketju, business case -analyysi

Muita tietoja

ABSTRACT
FOR THESIS

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Abstract

Industrial side stream utilisation is generating more interest nowadays and it's is being researched more and more. By-products and wastes might be suitable material for other processes, disposing them causes additional costs and part of the production costs have sunk into them as well. Research for new applications and utilisation possibilities is important, but at least as important is to examine the economic feasibility of industrial side stream utilisation.

This thesis focuses on side streams created by SMA Mineral's burnt lime and dolomite processes. Core of this work is to explore the utilisation of limestone processing side streams in the context of circular economy and examine the possible economic benefits of utilising them. Thesis aims to develop 2 or 3 value chain scenarios in which fine calcite, fine dolomite, filter ash and partly burnt lime generated in the processes is utilised. Business cases of selected scenarios are also presented, and rough financial analysis is done to estimate possible economic benefit of each case.

The research methods used are qualitative and descriptive for the most part. The most important part of the empiric research was the innovation workshop, where the value chain scenarios were selected and fleshed out. Interviews were conducted to supplement the workshop before and afterwards. Business cases of each scenario were presented to estimate possible economic benefit. Theoretic foundation was built by doing a literature review on circular economy and relevant concepts such as business ecosystems and value chains.

Three value chain scenarios were created and presented in this work: reactive surface structure, lake liming and granulation. Briquettes and granules showed most potential economic benefit (possible profit + disposal savings). Surface structure and lake liming were technically feasible and offered more economic benefits when compared to disposal.

Results of this thesis can be used to decide the next step to improve SMA Mineral's resource efficiency. They can be used to select possible topics for further research to continue to develop a scenario or to get additional information.

The results of this thesis are quite context specific. Chosen scenarios are susceptible for company location and goals. The results are also at this moment of time and they could be irrelevant in ten years because of major changes in legislation for example. However, methods used to select and depict value chain scenarios are suitable to research utilisation of other industrial side streams and analyse their economic feasibility.

Keywords: side streams, side products, by-products, waste, circular economy, business ecosystem, business model, value chain, business case analysis

Additional Information

Preface

This thesis explores feasibility of industrial side stream utilisation and focuses on key concepts such as circular economy, business ecosystems, business models and value chains. Three carefully selected value chain scenarios are presented for side streams of burnt lime production and dolomite processing and their economic feasibility is analysed. This work is part of the Master of Science studies in Process Engineering at the University of Oulu. This research took place between April 2018 and December 2018.

I would like to thank supervisors of this work, Harri Haapasalo and Pekka Tervonen, for their valuable advice and guidance during past months. Their feedback was extremely important during this process. I would also like to thank Johanna Holm and Veli-Matti Marttala from SMA Mineral for their help and support. A big thank you for everyone else at SMA Mineral and University of Oulu who helped during this research. I would not have been able to complete this thesis without all the help I got.

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Oulu, 12.12.2018 Oskari Rasila

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ABBREVIATIONS

EU	European Union
NPV	net present value
C/B ratio	cost-benefit ratio
ERR	economic rate of return
IRR	internal rate of return
CaO	calcium oxide
NP	neutralization potential
AP	acid potential

1 INTRODUCTION

1.1 Background

The modern economy still relies heavily on linear take-make-dump production model (Urbinati *et al.* 2017). This is very problematic from the environmental point-of-view as climate change and resource scarcity is becoming more and more pressing issues. The popular Earth Overshoot Day illustrates the overconsumption by calculating a yearly day when humanity's consumption reaches the limit of Earth's renewability. In 2018 this day was in early August and it has been taking place earlier every year. (Earth Overshoot Day 2018) It is estimated in paper "Roadmap to a Resource efficient Europe" (2011) by European Commission that with current rate of consumption equivalent of two planet Earths would be needed to meet the demand. The pressure on natural resources is likely to increase in the future as population grows and standard of living rises outside the western world.

Circular economy is a concept that has become very popular in recent years (e.g. Urbinati *et al.* 2017, Schulte 2013, Korse *et al.* 2016) as the need to reduce emissions, waste generation and improve resource efficiency has become more and more apparent. In circular economy, linear models are replaced with regenerative and restorative designs to maximize resource efficiency. Waste is minimized, and maximum value is created by recycling the materials in interlinked lifecycles of production (Nußholz 2017, Schulte 2013).

Vast amounts of waste are currently generated and there is a lot of underutilised potential in waste and side streams that can be harnessed in circular economy. For example, in the European Union a citizen generates approximately 4.9 tons of waste every year and in Finland an average of 17.5 tons of waste is generated per capita, over 60 % of which is caused by economic activities of mining and quarrying sector (Eurostat 2014). It is estimated that the European industry can save up to 630 billion euros a year by improving its resource efficiency (European Commission 2014). Thus, there is a strong incentive to study and improve resource efficiency across the borders of industries.

The potential economic benefit and on the other hand environmental pressure are directing more focus on waste and side stream utilisation (e.g. Ohenoja *et al.* 2018, Adesanya *et al.* 2018, Kinnunen *et al.* 2018). Moving from linear production to circularity can be a big change in a company's daily operations, requiring to rethink its whole process and business model. Change of this magnitude requires ability to evolve rapidly, and it is a characteristic of a successful company according to Moore (1993).

In limestone industry, there are several side streams that are inherent to the process. Like in any other extractive industry fine material is generated when stone is excavated, transported or otherwise handled and processed. Burning limestone generates filter ash and varying amounts of non-marketable calcium oxide also known as calcination waste or partly burnt lime. This thesis focuses on utilising side streams of limestone processing in a way that is both sustainable and economically feasible. Currently the side streams are not productized in a feasible way. There have been projects to study utilisation of these side products but so far, they have been unfeasible. This shows that there is a strong demand for a work which focuses on the economic feasibility of side stream utilisation.

1.2 Objectives

The main goal of this thesis is to find potential utilising scenarios for limestone processing side streams and evaluate their economic feasibility. This work aims to explore relevant concepts such as business ecosystems and value chains in circular economy context. The goal is to create a couple of interesting options for the side streams and define them so that their feasibility can be analysed. The goals of this thesis are fulfilled by answering the following research questions.

Research questions

I. How to analyse economic feasibility of industrial side stream utilization?
II. What are the value chain scenarios for limestone processing side streams?
III. What are the potential economic benefits of selected value chain scenarios?

The side streams this thesis focuses on come from the production process of SMA Mineral Oy. Environmental values are important to the company and it aims to operate sustainably and without harming the environment. They aim to improve their material efficiency and utilising the side streams feasibly is the key to achieve that goal. Feasible side stream utilisation reduces the pressure on environment because less waste is generated and less virgin materials are needed. In addition to disposal savings it is also possible for SMA Mineral to create new business from the side streams.

1.3 Research process

Well planned research process (presented in figure 1) is essential to ensure smooth progress of the thesis and its eventual completion. Precise and thoughtful framing of the research questions is important to direct the focus of the thesis towards relevant factors and to define the scope of the thesis as well. It is also important to use right research methods to answer the questions. Literature review, innovation workshop and business case analysis are the most important methods used in this work.

The research process starts with the literature review. It studies themes such as circular economy, business ecosystems and value chains. The review starts by focusing on circular economy before moving to explore other themes in that context. The aim is to present relevant concepts needed in economic analysis of side streams. This theoretic base is then combined with expert knowledge in the empiric part of the work.

The second part of the process is the empiric research. The goal of the empiric part of the thesis is to define possible value chain scenarios and describe them to set relevant context for the analysis. The information needed for selecting value chain scenarios is gathered from workshops and interviews. Another part of the empiric research is to define relevant business details for later economic analysis. Value chain scenarios are selected, and their ecosystems and value chains are outlined in the workshop. Interviews help to first explore possible utilisation scenarios and later to define relevant business case details.

The third part of the research process is the economic analysis of selected value chain scenarios. The economic feasibility is evaluated by presenting and analysing business cases of selected scenarios. This part of the process combines theoretical knowledge with the context and the expert knowledge. At the end of the research, it is good to evaluate the thesis itself as well.

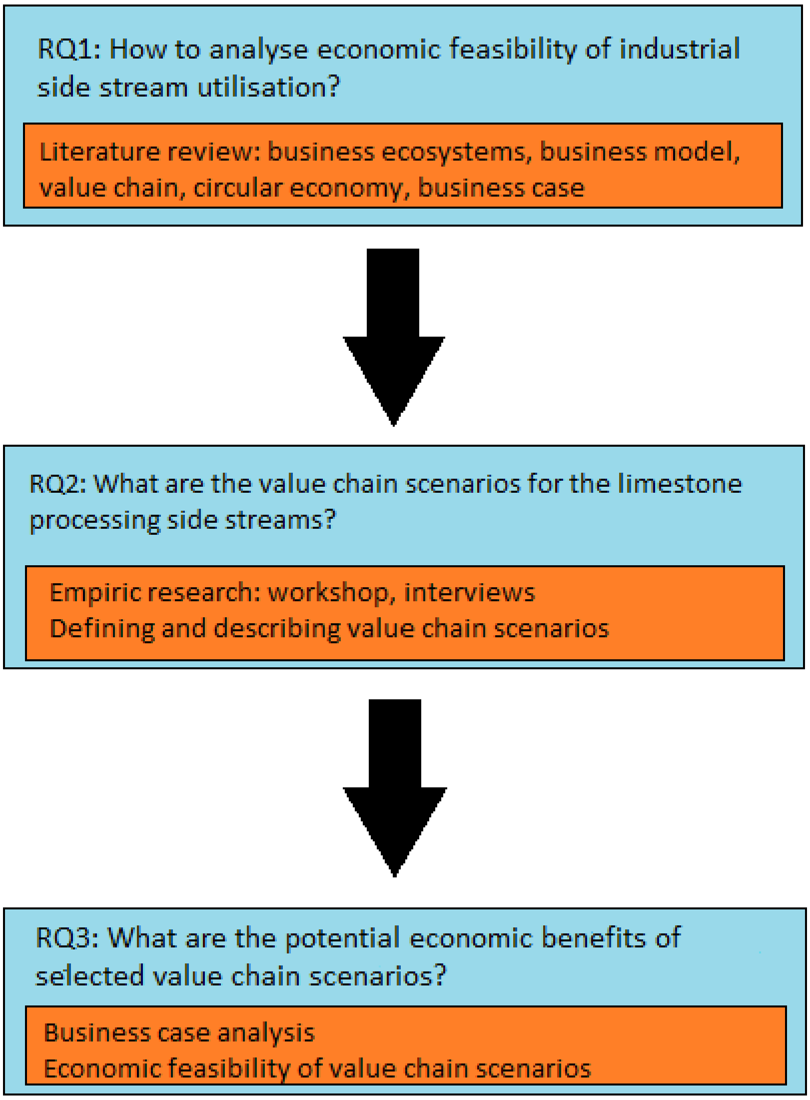

Figure 1. Research process.

2 LITERATURE REVIEW

This chapter presents the theoretic foundation of the work.

2.1 Circular economy

The modern economy is still for the most part based on linearity (Urbinati *et al.* 2017, Lewandowski 2016). Business models and supply chains are optimized to create products as efficiently as possible but there isn't really any circularity or sustainability to be found (Schulte 2013). Resources are extracted, goods produced and then used by customers and eventually dumped after they have served their purpose. Circular economy is a concept that could change that by reforming modern linear business models with closed loops and circular energy and material flows and new business models designed around these principles (Urbinati *et al.* 2017).

Many definitions for circular economy can be found in the literature (e.g. Korhonen *et al.* 2018). They vary a bit depending on the source but they all essentially describe circular economy as a concept that promotes regenerative and restorative design, recycling, waste prevention and resource efficiency. For example, Ellen MacArthur Foundation (2013) defines circular economy as "an industrial system that is restorative or regenerative by intention and design". Another description from Haas *et al.* (2015): "The circular economy is a simple, but convincing, strategy, which aims at reducing both input of virgin materials and output of wastes by closing economic and ecological loops of resource flows."

2.1.1 Principles of circular economy

Schulte (2013) sums up the concept of circular economy with five key principles:

- minimize waste
- identify and consider the whole ecosystem
- maximize flexibility
- use renewable energy
- maximize energy efficiency

First principle is to minimize waste. This can be done by focusing on product and process design. For example, striving towards standardized solutions, designing for disassembly and using less composite materials. Second principle is understanding the whole ecosystem of a business. Ecosystem is larger than just production and consuming and all parts of the product's life cycle should be covered. Third principle is to maximize flexibility through design. Product designing should consider things like ease of repair, modification and modular use. Fourth principle is to use renewable energy instead of fossil fuels. Lastly, it is important to maximize energy efficiency and this can be done by reducing the energy content of products. (Schulte 2013)

The circular economy changes traditional business ecosystems and business models. A circular economy replaces traditional linear model with a new pattern: resources-products-waste-renewable resources (Urbinati *et al.* 2017). It introduces strategies that encourage resource efficiency, reuse and recycling. A modern and sustainable ecosystem needs new key partners, key resources and key activities to create and deliver value effectively and according to the principles of the circular economy (Nußholz *et al.* 2017). This change requires things like reverse logistics to efficiently reuse goods and materials, change in buying process, instead of pay-per-own, business models should be built around pay-per-use model or product-service-system, and developing relationship with customers to promote the value of circular products. (Nußholz *et al.* 2017, Urbinati *et al.* 2017)

2.1.2 Waste and by-products

Relevant regulation in the context of this work are EU and Finnish regulation, latter of which is for the most part just implementing EU directives on national level. EU's Waste Framework Directive (2008/98/EC) and Finnish Waste Act (646/2011) give a legal definition of waste and by-products and presents specific conditions that substance must meet to be considered waste or by-product. Within European Union waste is considered to be a substance or object which is discarded by its owner. Waste is considered to be hazardous if it possesses at least one possibly dangerous property such as fire risk, explosion risk or risk of infection. Regulation also defines waste tax that has to be payed per ton of landfilled material. (European Commission 2008, Finnish Waste Act 646/2011, Finnish Waste Tax Act 1126/2010)

Waste Framework Directive presents a 5-step hierarchic approach to reduce waste generation (European Commission 2008):

- prevention
- preparing for re-use
- recycling
- other recovery, such as energy recovery
- disposal

Prevention includes all activities reducing the quantity of waste, the negative impacts on human health and the environment and the concentration of harmful substances in materials and products. Re-use means using products and components again for their conceived purpose. Preparing for re-use means checking, cleaning or repairing products for re-use without other pre-processing operations. Recycling includes reprocessing activities that convert waste material into products and raw materials. It includes reprocessing of organic material but not energy recovery. Recovery means utilizing waste material in a way that replaces other material. Disposal means discarding products or materials and any operation which is not considered recovery even if the operation recovers substances or energy as a secondary consequence. (European Commission 2008)

Regulation on waste also lays out conditions under which substances or objects are no longer considered waste. This set of conditions is called end-of-waste criteria. An object gains end-of-waste status and ceases to be waste if it has undergone recovery process and meets the following criteria (European Commission 2008, Finnish Waste Act 646/2011):

- it is commonly used for specific purpose
- there is a market demand for this purpose
- it fulfils technical requirements and meets relevant legislation and standards
- the use of this object does not have adverse environmental or human health effect

Regulation also draws a clear line between waste and by-products. A product or material is by-product and not waste if it is a secondary result from a production process primary goal of which is producing other product or material. By-product has to also fulfil following conditions (European Commission 2008, Finnish Waste Act 646/2011):

- further use is certain
- can be used as is or after normal industrial practices
- is created as an integral part of a process
- it fulfils relevant product, environmental and human health requirements and use will not cause negative impacts

It is important to note that legislation regarding wastes, side streams and disposal are likely to get stricter into future. Today's legislation and regulation is much stricter than 30 years ago, and this development is very likely to continue. For example, waste tax in Finland has been raised twice in recent years and it is currently 70 euros per ton up from 50 euros per ton, an increase of 40 % (Finnish Waste Tax Act 1126/2010).

2.2 Business ecosystems

One of the main characteristics of successful companies is the ability to evolve rapidly. They are able to effectively attract new capital and resources and connect with their suppliers, partners and customers to create vast networks of contacts around their innovation. Moore (1993) noted that these networks have clear similarities in nature and introduced the concept of business ecosystems. A company should not be viewed as a single entity of a single industry, instead, it should be viewed as a member of business ecosystem that can breach borders of industry. Zahra and Nambisan (2012) notes that an ecosystem consists of companies and other entities that interact with each other and whose value creation is characterized by interdependencies. The concept is illustrated in figure 2. A business ecosystem has no clear starting point. It evolves from capital, customer need and new innovation and move towards structured and complex network of interconnected stakeholders. (Moore 1993)

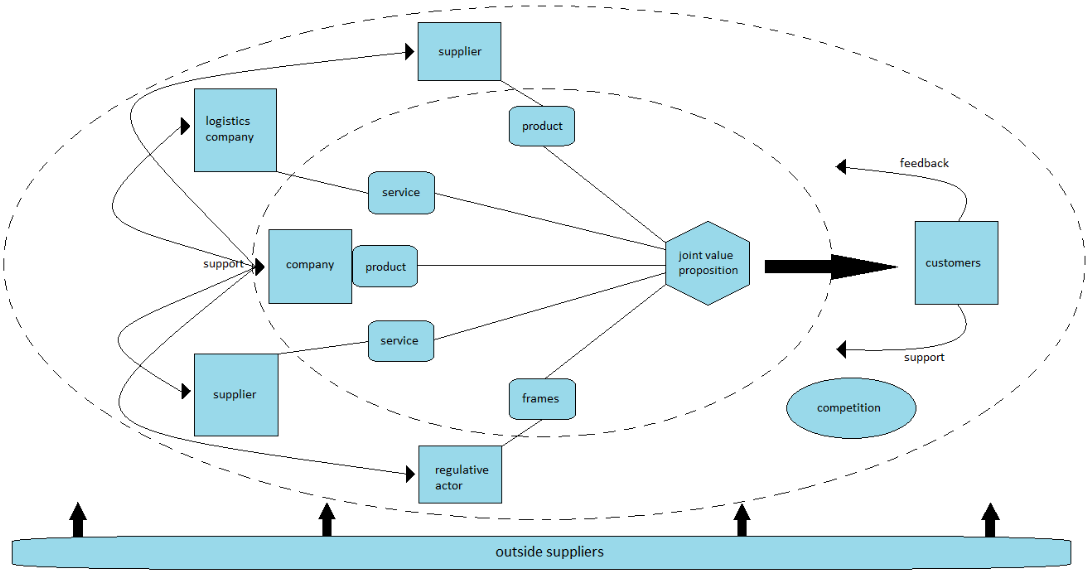

Figure 2. Business ecosystem (combined from Moore 1993, Gossain & Kandiah 1998, Frosch & Gallopoulos 1989, Schulte 2013, Hearn & Pace 2006).

A business ecosystem has four development stages during its lifecycle. The first stage is birth. A company that has new innovation works with its customers and partners to define value creation mechanism around its innovation. During birth stage it is essential for the company to protect its innovation against competing ideas and lock up key customers, suppliers and other channels. During this first stage it's not enough to merely satisfy the customer's need, but a leader should rise from the co-evolving members of the ecosystem to drive development. (Moore 1993)

After birth, the ecosystem must expand its market share. During expansion the company brings its innovation to a market with help from its suppliers and partners. The company's offer competes against similar offers and must dominate them in key market segments to take its place as the market standard. There are two conditions that area required for expansion stage to take place. First, the ecosystem needs an innovation that interests a large customer base. Second, this innovation must have enough scale-up potential to meet the market demand. (Moore 1993)

If the company manages to make its offer the market standard, it assumes the leadership of the ecosystem. During this stage of leadership the company must encourage its suppliers and customers to keep working to improve its offer. At the same time it must gather and maintain strong bargaining position compared to other members of the ecosystem. Bargaining power is gained by being the only source of key resources needed in the ecosystem. (Moore 1993)

The last stage of the ecosystem is inevitable and continuous self-renewal. The company must introduce new innovations to the ecosystem. At the same time it must lift and maintain high entry barriers to prevent possible rivals from forming a competing ecosystem. If the business ecosystem fails to renew, it faces death. There are three general approaches to self-renewal. First, the dominant member can try to prevent the rival ecosystem from growing or forming altogether. Second, they can absorb the threat into their own ecosystem. Lastly, they can reinvent themselves and restructure their organization to adapt to the new market situation. (Moore 1993)

A healthy business ecosystem offers its members predictable and stable relationships with other members and reliable value creation. There are three ways to evaluate the health of a business ecosystem: productivity, robustness and niche creation. Productivity means an ecosystem’s ability to continuously self-renew. This means transforming its technology and other inputs into new innovations to lower costs and create new value. One way to evaluate an ecosystem’s productivity is by measuring return on investment. Robustness describes an ecosystem’s ability to survive external disturbances and its predictability. There is only indirect ways of evaluating an ecosystem’s robustness, for example, by measuring the survival rates of members in a business ecosystem over time or relative to comparable ecosystems. Niche creation means an ecosystem’s ability to support diversity in it. A diverse ecosystem is better prepared to withstand external shocks and has better potential for innovation. Niche creation can be evaluated by measuring creation of valuable new functions in a business ecosystem. (Iansiti & Levien 2004)

2.2.1 Business ecosystem types

Purdy *et al.* (2012) identifies three different types of business ecosystems in their research: harbour and the fleet, the demand forum and multivalent sourcing. In the harbour and the fleet there is one key player who provides a platform (“a harbour”) to which other members of the ecosystem anchors themselves benefitting themselves and the harbour. Members who live off the platform are known as the fleet and they are usually small and medium-sized enterprises. The demand forum is similar to a clearing house. It brings together buyers and sellers in a market benefitting both parties. Multivalent sourcing is based on the inputs of production, such as capital, innovation, materials and talent. It improves the bargaining power of those who have material and talent and enhances informational advantages in sourcing capital and innovation. The idea of multivalent sourcing ecosystem is to connect those who have with those who need in an efficient way. (Purdy *et al.* 2012)

Zahra and Nambisan (2012) introduces four different models for business ecosystems in their research. Those models are the orchestra, the creative bazaar, the jam central and the mod station. In the orchestra model a group of companies work together to create value out of an innovation. This innovation is based on a platform that is provided and maintained by a key player in the ecosystem. In the creative bazaar a dominant member searches for innovation from smaller members and after finding a new innovation, it commercializes it. The jam central refers to a business ecosystem where a group of entities (such as research centres) work together to create completely new innovations and knowledge in an emerging or completely new sector of business. In the mod station model innovators create new applications to answer customer need in new markets or technological issues. A key player provides a platform for innovators to explore alternatives for existing products or services. (Zahra & Nambisan 2012)

2.2.2 Roles in business ecosystems

Iansiti and Levien (2004) identifies three different roles that can be found in a business ecosystem. They are a keystone, a dominator and a niche player. The nature of a business ecosystem is highly dynamic and the relationships between members of an ecosystem are constantly changing (Kandiah & Gossain 1998). This is why the business ecosystem roles are also dynamic and not set in stone. They can vary over time and also from domain to domain. (Iansiti & Levien 2004)

Keystones are the most critical members of any ecosystem. Their role is vital in the value creation mechanism of the ecosystem. A good keystone can have a great impact on the overall health of an ecosystem and its productivity, robustness and niche creation. If the keystone of an ecosystem is removed, it usually leads to the collapse of the entire ecosystem. They have a system wide effect but are just a small part of the whole ecosystem. Keystones prosper when their ecosystem prospers and this ensures their own survival. A keystone aims to create stability and value by providing a stable source of resources for common use. (Iansiti & Levien 2004)

Dominator also has a critical role in its ecosystem just like a keystone. But instead of fostering the overall prosperity of the ecosystem, it tries to exploit its crucial position for its own benefit. There are two types of dominators: physical and value dominators. Physical dominators try to take control of the ecosystem by integrating large parts of its value creation mechanism. Value dominators don't have lot of control nor do they desire for more. They create little or no value in the ecosystem but try to extract as much as possible from it. This eventually leads to the collapse of the ecosystem and their own downfall. (Iansiti & Levien 2004)

Niche players are the majority of a business ecosystem. They create most value in the ecosystem and are the driving force behind new innovations. Niche players uses common assets and resources provided by keystones and focus on their specialized niche. They create special functions and develop highly specialized capabilities in the ecosystem. (Iansiti & Levien 2004)

2.2.3 Risks related to business ecosystems

There are risks that are related to the type of a business ecosystem and risks that are related to the role a company takes in an ecosystem. There are also more general risks that comes from being part of a business ecosystem. Companies need to prepare for the risks they are going to face in a business ecosystem before entering and monitor their situation afterwards. (Smith 2013) The key factor to successfully operate in business ecosystems is to have a specific strategy to tackle the delays and challenges that are specific to the business ecosystems (Adner 2006).

General risks related to all types of business ecosystem are the complexity of relationship between members and the simultaneous cooperation and competition. Risks associated to the platform types of ecosystems are related to the potential loss of intellectual property rights, highly centralized control of common assets and resources and reciprocal interdependency between members and the keystone. Risks associated to both multivalent sourcing ecosystems and demand forum ecosystems is the possible replication of the business model. (Smith 2013)

There are three types of risk that are specific to the innovation ecosystems. Initiative risk is related to the uncertainties of project management. Interdependence risk means the uncertainty that is associated to coordinating with partners. It is the cumulative probability that all involved partners will be able to deliver their part of the project within a given time frame. Interdependence risk is assessed by multiplying the different probabilities of successful delivery. Integration risk is related to the cycles of adoption needed in different levels of the business ecosystem (suppliers, customers etc.) and it's assessed by adding up these cycles to estimate the overall delay. (Adner 2006)

Risks associated to participating in a business ecosystem are either general or role specific. General risks are related to the cooperation, competition and co-existence, to the relationships between members of the ecosystem and sudden changes in keystone's products and services that forces changes across the ecosystem. Risks related to the keystone role are the inevitable operating at the both ends of the supply chain and threats from new innovations. Risks related to the location of a business in the supply chain are either upstream risks (with component suppliers) or downstream risks (with complementors). (Smith 2013)

Smith (2013) suggests that companies should conduct a thorough inspection before entering an ecosystem to identify the initial risks and should have a real-time resource management to identify participation risks. Companies have to observe themselves to identify the crux of their competence and their target customers and organize themselves accordingly to survive (Kandiah & Gossain 1998). The risks a company faces is also dependent on the target market. There are usually several targets available to each innovation and their ecosystems can differ greatly from each other. This means that it is essential to have a complete view of the market situation and a clear understanding of the full ecosystem and its dynamic behaviour to create a successful strategy for entering and operating in a business ecosystem. (Adner 2006)

2.2.4 Circularity in business ecosystems

Circular economy will have a big effect on supply chains and value creation as it directs businesses from linearity towards circular strategies. Replacing linear supply chains with a circular model based on resource efficiency guarantees prosperity in the future despite population growth and finite resources (Schulte 2013). Business ecosystems are inherently linked to value chains. Kandiah and Gossain (1998) notes that the business ecosystem's primary goal is to great value through information, services and products and that they are built around value chains. This means that implementing circular strategies forces companies to rethink the value creation mechanism in their business ecosystem to ensure economic benefits (Nußholz 2017).

Most business models and thus business ecosystems of today are based on and optimized to linear system of take-make-dump (Nußholz 2017). Moore (1993) draws parallels between business networks and the ecosystems of nature. Reforming business ecosystems to fit circular economy principles can also take inspiration from the nature. As Schulte (2013) points out there is no concept of waste in the nature, everything is merely an input to another process in the ecosystem. Value creation in the ecosystem should be built on longevity and deliberate use of circular strategies (such as recycling products, parts, and materials). In a circular business ecosystem waste and side products are designed as inputs in interlinked lifecycles. (Nußholz 2017, Schulte 2013)

The key to establishing and maintaining a sustainable business ecosystem is continuous value capture. Hsieh *et al.* (2017) identified five main mechanisms that contribute to value capture. First, it is important that companies are constantly trying to enter new markets. This allows them to join with other ecosystems and to create new business models for value creation. Second, it can be very useful to take advantage of stakeholder networks (such as the entrepreneur's social network) to expand the ecosystem with relevant partners. Third, the meaning of brand image and corporate social responsibility activities is important. Promoting the values of sustainable development and using that to gain higher brand recognition among customers can be very valuable. Fourth, companies' capabilities and effort in research and development are important. They affect greatly companies' performance and may help to implement principles of circular economy. Lastly, it is crucial to be highly involved during the policy changing process to ensure that interests of company and its ecosystem are taken into consideration. (Hsieh *et al.* 2017)

2.3 Business models

Joan Magretta (2002) approaches the concept of business models in a poetic way. She defines the concept as a story that explains how the company works and defines the fundamental blocks around which its operations are built: customers, customer value, monetization and value delivery. (Magretta 2002) According to Osterwalder *et al.* (2005) business model is essentially a blueprint of a company's strategic positioning and goals and a plan for designing its business structure. To elaborate on that, a business model captures the value creation logic of a company by defining how it creates and captures value (Fielt 2013). Ahokangas and Myllykoski (2014) argues that business models are built around two key blocks which are the business opportunity and the competitive advantage. On the generic level, business models consists of similar blocks but in reality they are domain and company specific (Roos 2014).

Osterwalder and Pigneur (2010) identifies four core areas of business: customers, offering, infrastructure and financial viability. This structure is reflected by Fielt (2013) who notes that a business model should address customer dimension, value proposition, organizational architecture and economic dimension. The customer dimension identifies target customers and defines their problem. A value proposition is the benefit or the value that is delivered to the customer by using the offering of a company. The organizational architecture describes how the value proposition is delivered to the customer. The economic dimension consider things like revenue, margin and economies of scale. (Berndt 2003, Fielt 2013, Tsvetkova & Gustafsson 2012)

Achtenhagen *et al.* (2013) points out that business models are dynamic and they have to change over time to achieve sustained value creation. They argue that it is, in fact, essential for success. Only dynamic change takes advantage of new opportunities and reduces the risk of stagnation that usually follows a successful business. (Achtenhagen *et al.* 2013) Magretta (2002) notes that a successful new model can change the whole economics of an industry, giving its creator a strong competitive advantage.

Achtenhagen *et al.* (2013) identified three critical capabilities for achieving dynamic change of business model and they are presented in table 1.

Table 1. Critical capabilities for achieving dynamic change of business model (modified from Achtenhagen *et al.* 2013).

Critical capability	Related activity
Creating, identifying and experimenting with new business opportunities	Retrieving relevant information about technological developments, markets and competitors and monitoring changes Providing freedom for and encouraging the exploration of new ideas, which can lead into new projects Accepting the making of mistakes and encouraging learning from them
Using resources and capabilities in a balanced way	Choosing how to allocate the different resources in a balanced way Paying attention to further developing all different resource bases Ensuring a steady cash flow Striving after operational excellence to maintain low cost levels Reinvesting profits to facilitate further expansion Hiring or cooperating with people of specific skill sets to complement the competence base Investing into R&D and new product development Developing a brand's full potential by combining different marketing approaches
Achieving active and clear leadership, a strong corporate culture and employee commitment	Encouraging employees' expression of and search for innovative ideas and constructive questioning Developing and sharing clear values Showing loyalty and commitment to the employees Exerting a visible and credible leadership style Fostering employee motivation and commitment Focusing on open communication, e.g. communicating the value creation strategy across the company Involving employees in strategizing activities

All business models must be based on a valuable problem (Roos 2014). If business model is a solution without a problem, it is doomed to fail according to Magretta (2002). This leads to the conclusion that a root of successful business model is a valued solution paired with a valuable problem. These two parts are the fundamental thinking behind the concept of business model: the creation of value to customers and capturing part of this value (Fielt 2013).

Strategy must be separated from the concept of business model. While a business model paints a picture of a system and its pieces, it doesn't consider competition which is addressed by strategy. Essentially strategy defines the means of how a company is going to distinguish itself from its competitors. Strategy includes execution and implementation aspects of a business while the business model describes how the business system works in principle. The business model can be considered as a holistic view that includes the core areas of business and combines them into a one picture that defines the value creation logic of a company. (Magretta 2002, Osterwalder *et al.* 2005)

2.3.1 Value chains

Business models are essentially a tool to define the value creation logic of a company's business opportunity (Osterwalder *et al.* 2005). They are inherently linked to the concept of value chain as they are simply variations on the generic value chain according to Magretta (2002). Peric *et al.* (2017) points out that most business model definitions, despite their differences, are built around the concept of value and the elements linked to it. They argue that generic business model consists of value proposition, value capture, value creation and value network. A value chain defines the required activities for a company to produce and deliver its offering to its customers (Porter 2001). Berndt (2003) argues that the concept helps companies to identify their key resources and assets that give them competitive advantage and enables them to focus on value adding activities.

The generic value chain consists of primary activities and secondary activities supporting them. The primary activities are inbound logistics or inputs from suppliers, operations (production process), outbound logistics or delivering product to customers, marketing and sales and after-sales service. Supporting activities include the organization infrastructure, human resource management, technology development and procurement. (Berndt 2003, Porter 2001)

A company's value chain can be thought of as interconnected with the value chains of its key partners in the business ecosystem. These value chains form a value system which includes at least supplier's value chain, delivery value chain, and buyer's value chain. Tsvetkova and Gustafsson (2012) discussed the concept of value network which consists of interlinked value chains in different industries. They argue that a business model should focus on interlinked value chains that exist in an industrial symbiosis. The connected value chains form a value network that is very similar to the concept of business ecosystem. (Berndt 2003, Porter 2001, Tsvetkova & Gustafsson 2012)

2.3.2 Circular business model

The circular value chain is built on the principles of circular economy according to Roos (2014). It aims towards maximum resource efficiency by minimizing all inputs. Processing should be efficient and losses in energy, material and water balances should be minimal. Side streams and waste should be captured and their value potential utilised efficiently according to the waste hierarchy approach. (Roos 2014)

Roos (2014) discusses several ways to include circular strategies in to a business model. A company should try to accumulate today's side streams and waste that can be utilised as resources in the future. Offerings should be designed for reuse. Non-renewable and hard to recycle material should be replaced with renewable and recyclable inputs. A paradigm shift needs to take place and business model's value capture should be designed around functionality or use instead of ownership. (Roos 2014)

Much like Hsieh *et al.* (2017), Roos (2014) notes that continuous value capture is essential for a circular business model. An efficient value chain is needed so that every step of transformation process from inputs to delivering an offering adds value to the system. This is challenging because there can be several side streams that need to be monetized. (Roos 2014)

Urbinati *et al.* (2017) recognized four levels of circularity in general business models. First, there are traditional business models that are completely linear and doesn't apply circular economy principles in any way. Second, there are downstream circular business models which have implemented pricing or marketing based on use and re-use of their products. Third, there are upstream circular business models that have implemented these principles in their designing process and supply chain. Finally, there are completely circular business models where circular economy principles are implemented throughout the value creation and capturing process. (Urbinati *et al.* 2017)

According to Rizos *et al.* (2016) the most prominent barriers that small and medium-sized enterprises (SMEs) face when transforming their business model towards a circular business model are lack of support from supply and demand network and lack of capital. About 50 % of SMEs in the research cited either lack of support from supply and demand network or lack of capital as a barrier they had faced when implementing circular economy principles. Lack of supply manifested as an absence of needed suppliers (following circular economy principles in their own business model) in the production process. Lack of demand manifested as a need to promote and prove the value and quality of green goods and services to the potential customers. Lack of capital refers to variety of capital related issues such lack of initial capital, trouble of finding funding other than private and bank funds, costs related to research & design work needed to develop green products and services. (Rizos *et al.* 2016)

Rizos *et al.* (2016) also found enablers that have been recognized in SMEs implementing circular economy. The most prominent enabler was company's environmental culture that was cited by about two-thirds of the enterprises. The commitment and environmental mindset of the workforce is major factor in the transition to a circular economy business model. Other prominent enablers are networking and support from the demand network which were cited by around 30 % of SMEs. Networking was understood as joining like-minded enterprises striving for sustainability. Support from the demand network manifested as customer base's need or preference for green products and services. (Rizos *et al.* 2016)

2.3.3 Business model framework

Osterwalder *et al.* (2005) presented a framework for business models that includes nine building blocks and four fundamental pillars, reflecting the four main areas of any business. Product pillar includes value proposition block and it describes the company's offering. Customer interface pillar includes three blocks which are target customer, distribution channel and relationship. The pillar identifies the customer segment the company seeks to serve, the ways it is going to use to interact with its customers and explains the nature of the relationship between the company and its customers. Infrastructure pillar has also three blocks: value configuration, core competency and partner network. It describes the activities and resources required for value creation, identifies the key areas of competence required in the business model and describes the necessary suppliers and other partners of the ecosystem. Financial aspects pillar consists of two building blocks: cost structure and revenue model. It defines the costs that are relevant to the business model and describes how the company makes money in the business model. The nine business blocks are presented in table 2. (Osterwalder *et al.* 2005)

Table 2. Business model building blocks (modified from Osterwalder *et al.* 2005)

Pillar	Business model building block	Description
Product	Value Proposition	Gives an overall view of a company's bundle of products and services.
Customer Interface	Target Customer	Describes the segments of customers a company wants to offer value to.
	Distribution Channel	Describes the various means of the company to get in touch with its customers.
	Relationship	Explains the kind of links a company establishes between itself and its different customer segments.
Infrastructure management	Value Configuration	Describes the arrangement of activities and resources.
	Core Competency	Outlines the competencies necessary to execute the company's business model.
	Partner Network	Portrays the network of cooperative agreements with other companies necessary to efficiently offer and commercialize value.
Financial Aspects	Cost Structure	Sums up the monetary consequences of the means employed in the business world.
	Revenue Model	Describes the way a company makes money through a variety of revenue flows.

Osterwalder and Pigneur (2010) presented a tool for designing a business model called The Business Model Canvas. It is an illustrative tool that helps to define relevant aspects of a business model. The heart of the canvas is the value proposition – the benefit for the customers. The left side of the canvas includes key partners, key activities and key resources required to fulfil the value proposition. It also outlines the cost structure of the business model. The right side includes customer segments, relationships with them, distribution channels and the revenue streams included in the model. The business model canvas is presented in figure 3. (Osterwalder & Pigneur 2010)

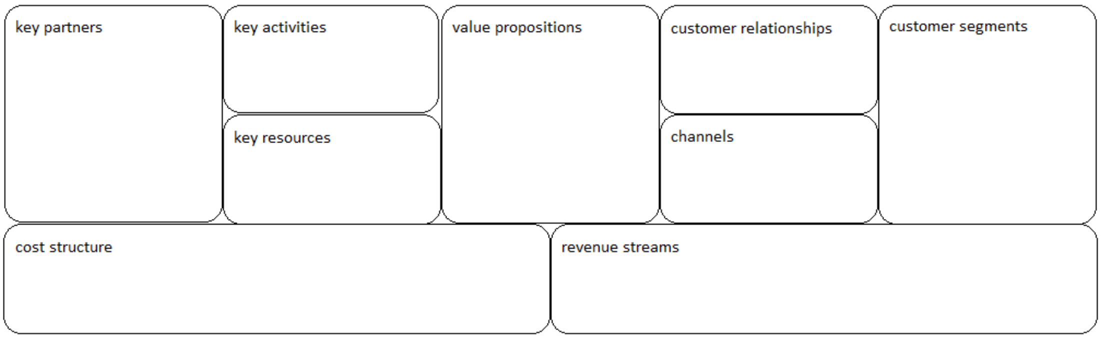

Figure 3. Business model canvas (modified from Osterwalder & Pigneur 2010).

2.4 Analysing industrial side streams

2.4.1 Business case analysis

Based on the literature review, business case is a very common and useful method to describe a potential project or investment and then evaluate its feasibility. According to Rasche and Seisreiner (2016) the concept was first used at Harvard Graduate School of Business Administration in 1920s. Essentially, the business case defines the investment proposition and improves the investment's possibility to succeed (Korse *et al.* 2016, Berghout & Tan 2013). It includes clear reasoning for the business and the economic part of the investment (Business Case Pro 2010). Business case can save resources by focusing the attention to the critical parts of the project and helps to identify unviable ideas before committing lot of resources (Berghout & Tan 2013).

Business case analysis is a method to analyse possible investments and projects. Its main goal is to highlight economically feasible projects using rational reasoning. Kinnunen *et al.* (2011) noted that business case analysis contains three main elements which are the market assessment, technical assessment and financial analysis. In addition, it is usually important to assess the strategic fit of the evaluated proposition as well. (Kinnunen *et al.* 2011) A generic framework for business case analysis is illustrated in figure 4.

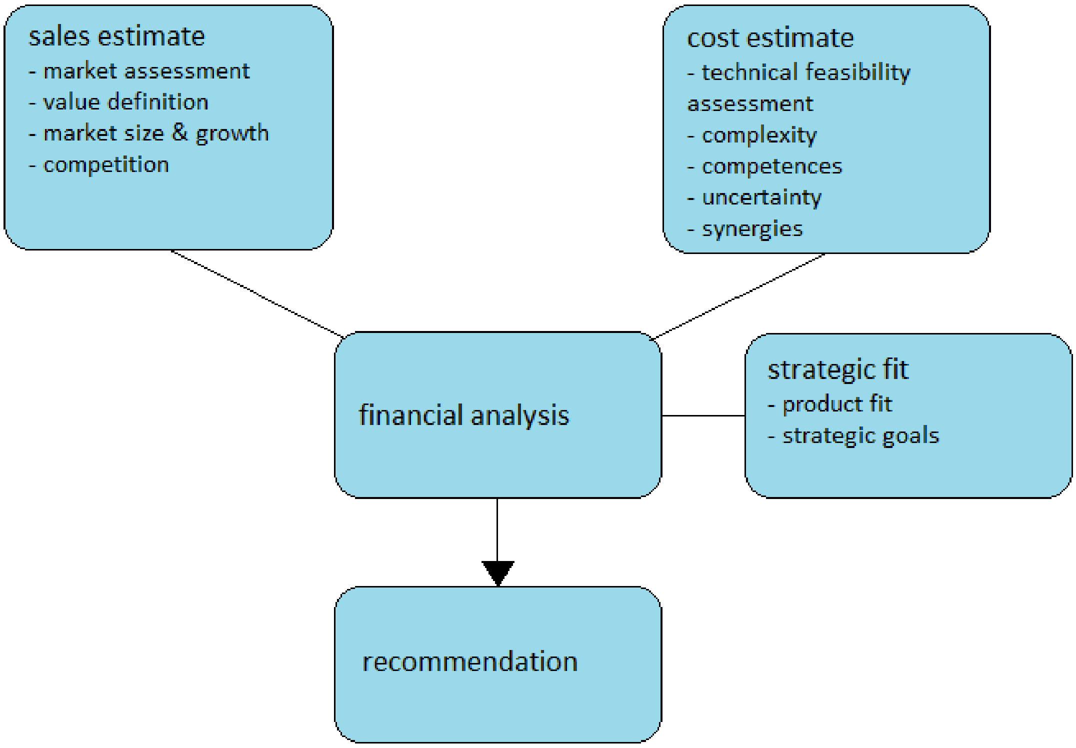

Figure 4. Business case analysis (modified from Kinnunen *et al.* 2011).

Market assessment has two parts. First, it defines the value of the proposed investment. It identifies the customer need, benefits of the proposition and its value and the opportunity window. Second part of the market assessment focuses on the market itself. It is crucial to identify the target market, the size of it and its possible growth rate. It is also important to consider the competition in the target market. Technical assessment explores technical complexity of the project, availability of required capabilities and skills to fulfil it, seeks possible technical synergies and gives estimation of the total work effort needed to convert the idea into a completed project. Financial analysis focuses on using the information gained during market and technical assessment. It calculates sales and cost estimates based on the work done in previous stages. Market assessment lays the foundation for sales estimate and technical assessment for cost estimate. Financial analysis combines that information and presents a numeric value on the economic feasibility of the business proposition. (Kinnunen *et al.* 2011)

After identifying the customer need and value, assessing the market situation, studying of technical requirements and work effort and estimating economic benefit of the project, it is important to consider the strategic fit of the possible investment. Assessment of strategic suitability should compare the potential investment from the aspect of a company's products and technologies. It should explore whether the project fits with other projects or products of the company and identify possible overlaps, contradictions and even cannibalization. Strategic evaluation should also consider if the project or investment fits with the strategic goals of the company in general. (Kinnunen *et al.* 2011)

Doing a good, balanced and thorough business case can be very challenging and there are several difficulties that need to be overcome in the process. One of the biggest obstacles is the fragmented information required for the analysis. One needs to search for it via various sources and after finding the relevant pieces, they need to be combined into a clear and representable picture of the business proposition. Another source of uncertainty is the market assessment as the estimation of the market situation can be unreliable because the actual market acceptance of the product is unknown. There is also uncertainty related to cost and sales estimate, therefore, it is important to verify the estimates using either historical or comparable data if possible. (Kinnunen *et al.* 2011)

Rasche and Seisreiner (2016) argue that business case analysis is essentially a process with four steps while Business Case Pro (2010) introduced 12-step checklist for writing a business case. Based on their frameworks the general business case process starts by identifying the problem or the business need. Then, the solution or the investment is described and a couple of alternatives are also outlined. Next, the pros and cons of the investment or the solution are evaluated by estimating cost and sales figures for each of the possible solutions and the uncertainty of the project is considered. After weighing the pros and cons, the strategic fit of the investment is explored. Before recommending any of the options it is good to objectively assess the quality of the business case itself. (Rasche & Seisreiner 2016, Business Case Pro 2010)

Most business case elements and frameworks don't seem to include sustainability in any way in the evaluation process, but it is an important aspect to consider now that resource efficiency and circular economy are hot topics. Korse *et al.* (2016) developed an enhanced business case framework for sustainability by including principles of circular economy into their work. They argued that all circular economy principles cannot be applied in every case because each business case has its own specific context and thus, identified three core elements for assessing environmental sustainability: resource usage, ecological footprint and environmental impact. (Korse *et al.* 2016)

The business case model presented by Korse *et al.* (2016) has five domains and one universal constituent. Domains that are covered are technology, strategic, stakeholders, financial and environmental sustainability. Environmental sustainability is included as a separate constituent to ensure that the complex, intangible effects related to it are taken into consideration. Their work also includes risk analysis of each domain. Each domain should be assessed by using at least three separate indicators. The framework and general indicators are presented in table 3. (Korse *et al.* 2016)

Table 3. Business case for sustainability (modified from Korse *et al.* 2016).

Technology	Stakeholders	Strategic	Sustainability	Risks
Functional requirements	Stakeholder dependency	Business goals alignment	Resource usage	Economic
Physical requirements	Stakeholder collaboration	Chain partner alignment	Environmental impact	Technology
Operational requirements	Stakeholder responsibility	Governmental alignment	Ecological footprint	Stakeholder
				Strategic
				Sustainability

2.4.2 Cost-benefit analysis

Another method to evaluate business proposals or projects is cost-benefit analysis. It is used especially in governmental decision making regarding new policies and regulations. The basic principle of cost-benefit analysis is to identify relevant benefits and costs of a project and compare them to calculate net benefit of a business proposal (Boardman *et al.* 2006). Cost-benefit analysis method relates the costs with the monetary benefits gained by going through with a project and gives each considered option a monetary value (Cellini & Kee 2010). The process is presented in table 4.

Table 4. CBA process (modified from Boardman *et al.* 2006, Cellini & Kee 2010)

1. Describe status quo, identify alternatives
2. Identify relevant stakeholders, whose costs and benefits counts
3. Identify and categorize costs and benefits
4. Predict costs and benefits over the life time of the product
5. Give costs and benefits monetary value
6. Discount the impacts to obtain present values
7. Calculate net present value of each alternative
8. Sensitivity analysis
9. Decision

Cost-benefit analysis can be done anytime during a projects life time. Ex ante or prospective analysis takes place before the start of a project to compare different alternatives and assess whether an investment decision should be made at all. An analysis can be done during the project as in median res or snapshot analysis. It evaluates the start of the project and assess whether current benefits are bigger than the costs of completing the project. Ex post or retrospective analysis is done after the project is completed. It gives information on overall success of the project and can give useful comparison for similar projects in the future. Cost-benefit analysis can also be done as a comparison by using two methods, for example comparing ex ante and ex post analysis. It is a useful way to assess the accuracy of analysis and to gain information on possible errors done during analysis. (Boardman *et al.* 2006, Cellini & Kee 2010)

Cost-benefit analysis can be done either from purely financial point-of-view or including social point-of-view as well. Financial analysis only considers the costs and benefits of the company or organization itself and ignores everything outside that scope. This means that, for example, environmental costs are left outside of the analysis and all the other intangible and indirect costs and benefits as well. Social analysis takes a more holistic approach and tries to include everything related to the project. This means that cost-benefit analysis should consider costs and benefits affecting other stakeholders, customers or the environment and not focus solely on the company. (Cellini & Kee 2010)

The cost-benefit analysis process starts by setting the framework for the analysis by identifying the alternative solutions and describing the status quo. Then, one needs to decide whose costs and benefits are relevant. After relevant parties are recognized, costs and benefits are identified and categorized. Fourth step of the process is to predict costs and benefits over the project's life and project possible changes in them. Next, all the impacts are given a monetary value, also nature of the impact, measurement technique and assumptions made should be explained. Sixth step includes discounting the impacts to obtain present values. Then, the net present value of each option is calculated. Before making a decision, a sensitivity analysis should be conducted to assess risk and uncertainty of the project. (Boardman *et al.* 2006, Cellini & Kee 2010)

Cost-benefit analysis recommends a course of action usually based on net present value (NPV). It is in general the best tool to use for reasoning as it gives clear answer whether an option is economically feasible or not. Other possible indicators are cost-benefit ratio (C/B ratio) and economic rate of return (ERR)/internal rate of return (IRR). C/B ratio is calculated by dividing NPV with NPV of costs. It is useful to compare projects of similar size but it may hide scale differences. ERR is basically the discount rate that gives total present value benefits equal to costs. Usually it is recommended to use NPV for recommendations. (Cellini & Kee 2010)

Boardman *et al.* (2006) identified four main sources for error in cost-benefit analysis in their book. Omission errors happen when some sources of benefits or costs are excluded from the analysis. It can also mean double counting of some impacts. Forecasting errors relate to difficulties in predicting the future. It is usually caused by sudden, unseen technology change, cognitive bias of the analyser, changing project specifications or for strategic reasons. Valuation errors happen when indirect, intangible impacts are priced because information is often uncertain. Measurement errors are related to inaccuracy in observing, recording or interpreting impacts. The impact of errors is usually biggest in ex ante analysis and diminishes as the project continues so that the smallest impact is in ex post analysis. (Boardman *et al.* 2006)

2.4.3 Sensitivity analysis

Because there are lot of assumption, predictions and projections involved when investigating possible business opportunities, it is important to consider the uncertainty of the proposal. Saltelli (2002) sums up sensitivity analysis as a method to study uncertainty in a model's output and explore which inputs are the most prominent sources of uncertainty.

There are three ways to conduct a sensitivity analysis, according to Boardman *et al.* (2006). Partial sensitivity analysis is the simplest. It is done by changing one parameter at a time and useful for finding break even points for example. Usually the most critical or uncertain parameters are manipulated. Worst- and best-case scenario is done by assessing the project by using the assumed best-case values for parameters and also the worst-case values. If a project looks good even in the worst-case scenario it means the project isn't especially risky and vice versa, if a project doesn't do well in best-case scenario it is quite risky and not very lucrative. There is also Monte-Carlo simulation that uses probability distributions for uncertain assumptions. It requires a lot of computing, data and work, thus Cellini and Kee (2010) argues that it shouldn't be used in normal situations. (Boardman *et al.* 2006)

2.5 Literature review synthesis

Utilizing industrial *side streams* as raw material might not be as straightforward as using virgin material and there are several specific aspects that need to be taken into consideration. Legislation and regulation set the framework for *wastes* and *by-products* by defining them and give the conditions under which wastes, and by-products can be considered as secondary raw material. Legislation will probably become stricter and stricter in the future and punish for resource and energy inefficiency (e.g. carbon tax, waste tax) and reward for efficient use of resources and minimizing waste and emissions by applying principles of *circular economy* (renewable energy, recycling, reuse etc.).

There are, however, things that make utilisation challenging. *Side streams* and *waste* are often heterogeneous leftovers from the actual production process. Because their composition might not be ideal for planned reuse, additional costs might incur if pre-processing is required. And even after pre-processing (e.g. drying, milling, screening) secondary raw material might be lower quality than virgin material. This is the case for example in paper production where properties of recycled pulp are lower than those of virgin pulp (Gulsoy & Erenturk 2017, Lee *et al.* 2016). The amount of secondary raw material generated can also vary quite a lot and this can be problematic if utilisation needs a constant amount of material. Transport is another major thing to consider. It would be ideal to utilise side streams near their place of production instead of transporting them across the country because that brings a lot of additional costs and might make their use unfeasible.

Based on the literature review a three-level approach is needed to get a holistic view on side stream value propositions and value creation and value capture mechanism built around them. First level is the general level – "the bigger picture" which is represented by *business ecosystem*. This concept was first introduced by Moore (1993) who compared networks made by interlinked companies with ecosystems found in nature. *Business ecosystem* concept allows to describe relevant stakeholders such as regulatory actor, partners, customers that are required to create and capture value. Every company in an ecosystem has their own, unique *business model* and to have a healthy ecosystem they all need to be able to create value for themselves. Osterwalder and Pigneur (2005) describes *business model* as a blueprint which captures a company's strategic positioning, goals and business structure. In the heart of every *business model* there is a *value proposition* which tells how the customer is going to benefit using the product or the service. Generic *business model* identifies value creation, value capture and value network that are needed to fulfil the value proposition and capture a part of the value for the company (Peric *et al.* 2017). *Business model* is built around the *value chain* which is essentially the same as value creation part of a business model. *Value chain* describes the required activities needed to create and deliver the offering to customers.

Business case combines all three levels into a one coherent picture in the right context. Building a business case starts from value proposition and identifying key activities required to fulfil it. *Business model* is sketched around *value chain*. Fielt (2013) notes that *business model* is the answer to the question how the company can create value to customers and how it can capture part of that value. *Business model* should describe critical partners and value capture mechanism. *Business case analysis* (figure 5) is done at this point to gain objective and rational information on economic feasibility of an investment or a project opportunity.

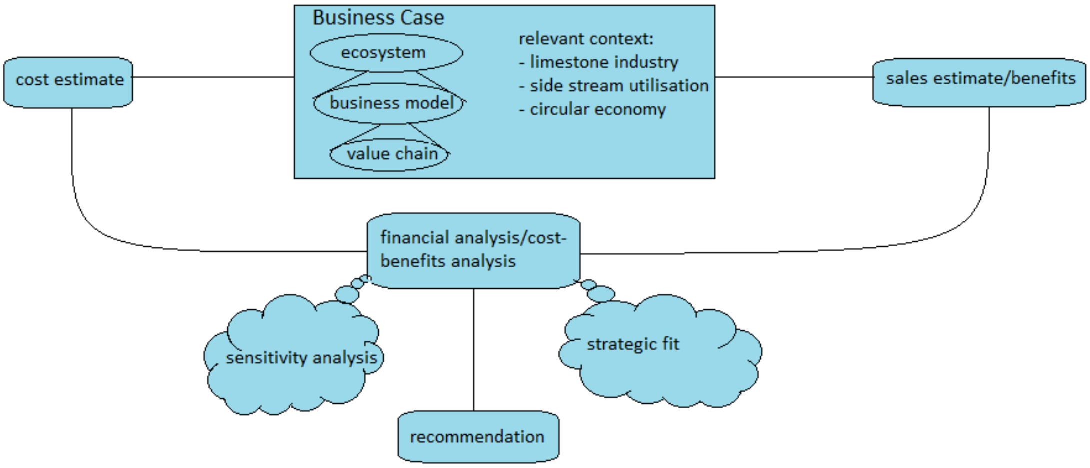

Figure 5. Business case analysis.

In the context of this work, it is important to note that utilization of *side streams* and *waste* can be seen as an alternative cost to disposing them. *Waste* and *side streams* can be viewed as negative externalities of production processes. They can be converted into goods by applying principles of *circular economy* and thus extract more value out of the production process. Instead of landfill, more value is kept within the economy by utilizing *side streams*. Investing into a landfill site brings costs (e.g. construction, permits, transport and handling, required supervision) that can be avoided if the side stream material can be utilised instead. If the disposed *waste* is categorized as dangerous then landfilling costs increase because there are specific requirements for constructing, using and controlling such a landfill site.

3 VALUE CHAIN SCENARIOS

This part of the work focuses on empiric research which will answer research question 2 ”What are the value chain scenarios for limestone processing side streams?”.

3.1 Research method

The aim of the empiric part is combining theoretical foundation built in literature review with the practical setting of the work. In theory synthesis it was noted that a three-level approach is needed to adequately describe a utilisation idea. First, on general level the key members of the ecosystem are required. Then, a business model needs to be sketched out by defining a value proposition, cost structure and revenue streams. Finally, a value chain is needed to capture key activities for fulfilling the value proposition.

Research method (presented in figure 6) relies heavily on an innovation workshop and interviews. These methods suit this kind of problem very well because expert knowledge and insights are required. The workshop was the most important part of the empiric research in this work because it was used to select and describe the value chain scenarios. Interviews were used as a complementary tool before and after the workshop. There was also additional material from previous projects of SMA Mineral and that was studied and used to explore possible utilisation ideas.

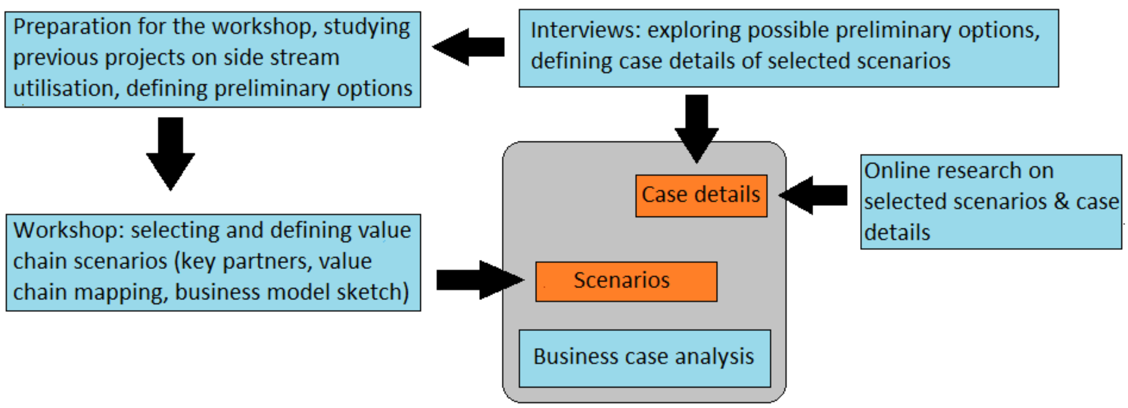

Figure 6. Research method for the empiric part of the work.

The workshop was held at Röyttä. There were nine participants altogether, most of them from SMA Mineral. Participants:

- Johanna Holm, SMA Mineral
- Veli-Matti Marttala, SMA Mineral
- Pasi Naukkarinen, SMA Mineral (via skype)
- Kimmo Hirvikallio, SMA Mineral
- Sampsa Vuori, SMA Mineral
- Lasse Untinen, SMA Mineral
- Juho Kinnunen, SMA Mineral
- Henna Longi, Oulun yliopisto (via skype)
- Oskari Rasila, thesis worker

The participants offered a lot of experience and knowledge of the limestone industry. There were both sales persons and production experts present at the workshop. The mix was very good for discussing both major aspects of a business proposition – financial and technical. Sales persons had great insights on things affecting revenues streams, market potential and competition. Production experts had valuable comments on realism of different ideas, investment needs and research need. Academic researcher offered additional insights on describing ecosystems and value chains and cooperation with universities and research institutes regarding projects with public funding.

The workshop had multiple goals. The first goal was to select two or three value chain scenarios that seemed to be the most promising. Second goal was to describe the selected ideas using the three-level approach of ecosystem, business model and value chain. This included identifying required key members of the ecosystem, defining the value proposition, cost structure and revenue streams and sketching a value chain for each of the ideas. Third and final goal was to discuss market potential, technical feasibility and strategic fit of the selected ideas. The idea was to, for example, identify required business case details but also possible things that might need additional research after the workshop.

The workshop was planned for half a day and it was fully spent. The first task was to select the most promising ideas. In total, eight ideas were presented and discussed.

These were reactive surface structure, bio granules for water treatment, lake liming, stabilization of soil and treatment of sulphate soil, filler material (e.g. for concrete, asphalt), building board, granulation of side streams and production of calcium compound (such as calcium nitrate). The selection was done via open discussion and brainstorming to highlight positives and negatives of each idea. After selection the following tasks was to identify required key members of each idea to sketch out the ecosystems, outline a rough business model and define the value chain of each idea. These tasks were fulfilled with more structured discussion where one topic was brought up at a time. The final task was assessing market potential, technical feasibility and strategic fit of the selected ideas. Once again, a more structured discussion was used, and ideas were handled one at a time.

The results of the workshop were satisfactory, and it fulfilled its goals. The selected ideas were reactive surface structure, lake liming and granulation of side streams. They all have in common potential for large volume, they are new fields in Finland and would not cause serious competition issues. Other ideas had their positive and interesting aspects as well but were in the end rejected for various reasons. The bio granule scenario was deemed to be too small scale as it only used small amounts of side streams as binders. Building board scenario needed a lot of research and the end products would not have that much of value despite needing intensive pre-treatment (e.g. milling, drying). Filler material and stabilization/treatment of soil were rejected because they would be in direct competition with SMA Mineral’s other products. In the soil scenario long distances were also a negative factor as most stabilizing is done in southern Finland and most of the sulphate soils are also in South Western coasts of Finland. Production of calcium nitrate would need big investments and was deemed too unrealistic and thus rejected.

The other tasks were also successful. Key members of business ecosystems were identified. Value propositions were defined along with costs and revenues. Key activities were also identified and attributed to responsible member of the ecosystem to form a value chain. These ecosystems and value chains are presented later in this chapter. In the workshop it was also discussed that the focus actor should be SMA Mineral, thus costs and revenues and such should be examined from the company’s point of view.

In addition to the workshop, interviews were conducted either in person or via email. They were used to explore possible utilization ideas before the workshop and to gain additional information on selected scenarios afterwards. Interviews conducted in person were informal without a predetermined list of questions while email interviews had a list of question that the person interviewed would answer.

3.2 Side streams

This work focuses on side streams of burnt lime production at Röyttä and dolomite mining and processing at Kalkkimaa. There are three side streams in burnt lime production. The most prominent is fine calcite that is screened before feeding raw material into the lime kiln. Fine calcite is under 20 mm in particle size. The kiln feed is 20-40 mm and finer material is not suitable for the kiln. Another side stream that is integral part of production is filter ash. Filter ash is separated from flue gases with a fabric filter. Third side stream is partly burnt lime (or calcination waste) which doesn’t fulfil quality standards. Partly burnt lime is produced during malfunctions, shutdowns and start-ups of the kiln. Fine dolomite is created when dolomite is milled, crushed and screened. Dolomite is calcium carbonate, magnesium content of which is over 10 %. (Ahma Ympäristö Oy 2015a, Rapakko 2016)

There are thus four side products that are considered in this thesis – fine calcite, filter ash, partly burnt lime and fine dolomite. In addition to that filter ash have been mixed with fine calcite until 2012 but it isn’t generated anymore. Currently there are large amounts of side products stored at Röyttä and Kalkkimaa waiting for utilization or disposal. At Röyttä there are 60 000 tons of fine calcite and 60 000 tons of mixture of fine calcite and filter ash. At Kalkkimaa there are 30 000 tons of fine dolomite and 30 000 tons of partly burnt lime. (Ahma Ympäristö Oy 2015a, Rapakko 2016)

Approximately 10 % of calcite is too fine for the lime kiln. With current production rate about 40 000 tons of fine calcite is produced a year. Weather has a big effect on the amount and dryness of fine calcite. 7 – 12 000 tons of fine calcite is captured dry. About 5 000 tons of filter ash is captured from flue gases yearly. As mentioned before filter ash is no longer mixed with fine calcite so the mixture of calcite and filter ash is no longer generated. The amount of partly burnt lime varies greatly depending on malfunctions and maintenance shutdowns. In general, it is between 1 000 – 22 000 tons a year. Approximately 15 000 tons of fine dolomite is generated every year. (Ahma Ympäristö Oy 2015a, Rapakko 2016)

Part of the by-products are utilised already in SMA Mineral’s Cresco products for agriculture. Dry fine calcite can be utilised fully, it is sold for example as cattle feed lime and for power plants. Milled fine calcite, filter ash and partly burnt lime is used in the company’s Cresco products for agriculture. Fine dolomite is also used in Cresco products. Some of the partly burnt lime can be sold as is to customers whose quality requirements are not very strict. (Ahma Ympäristö Oy 2015a) In the environmental permit applications for extractive waste disposal, Ahma Ympäristö Oy (2015a) estimated that with current utilization and production rates approximately 6 – 35 000 tons of fine (wet) calcite, 2 500 – 5000 tons of filter ash, 700 – 2 700 tons of partly burnt lime and 0 – 5 000 tons of fine dolomite is accumulated every year.

All of these side products are non-acid forming and their NP/AP ratio is over 3. NP stands for neutralization potential and AP for acid potential and their ratio is used to evaluate acid forming potential of material. The side products are alkaline, and they have a quite good neutralization capacity. (Ahma Ympäristö Oy 2015a) According to Rapakko (2016) fuel oil and recycled oil was used as lime kiln fuel at Röyttä until 2014 when oil was replaced with coal gas. This improved the quality of filter ash and partly burnt lime. Improvements can be seen from sulphur contents and acid potential of side stream samples before and after the change. Both have reduced notably after the fuel change. For example, partly burnt lime’s AP number has dropped from over 3 to under 0.5 and its sulphur content from over 0.1 % to less than 0.01 %. (Ahma Ympäristö Oy 2015a)

If SMA Mineral’s side streams cannot be utilised, they must be disposed according to Finnish legislation. Side streams would be considered as extractive waste and disposed at separate extractive waste disposal site. Ahma Ympäristö Oy (2015a) has categorized side streams as follows in the environmental permit application: fine calcite (waste code 10 13 01) as permanent waste, partly burnt lime (10 13 04) as ordinary waste, filter ash (10 13 13/12) as ordinary waste, fine dolomite (01 01 02) as permanent waste and the mixture of fine calcite and filter ash (10 13 06) as ordinary waste.

It is possible that partly burnt lime and filter ash would be considered as hazardous waste. Burnt lime (CaO or calcium oxide) has a hazardous property H4 (irritating) and it is given hazardous clauses H315 (irritates skin), H318 (serious risk of eye injury) and H335 (may irritate respiratory tracts). According to the environmental permit application by Ahma Ympäristö Oy (2015a), waste may be considered as hazardous based on property HP4 (irritation of skin and eyes) if waste in question includes more than 10 % material that can cause eye injuries (code H318). Filter ash and partly burnt lime slightly exceed that limit. (Ahma Ympäristö Oy 2015a)

According to Finnish Waste Tax Act (1126/2010), tax is paid for every ton of disposed waste that is listed in waste tax schedule and the tax is 70 euros per ton. Based on Ahma Ympäristö Oy (2015a) categorization of the side streams, they are not in the tax schedule and therefore no taxes would need to be paid for disposing them.

3.3 Scenarios

Like mentioned earlier, reactive surface structure, lake liming and granulation (or briquetting) of side streams were selected in the workshop as the most promising utilisation ideas. This sub chapter will describe these ideas in more detail. Their ecosystems' key members are presented, and their roles are explained shortly. Value chain of each idea will be illustrated as well. It will make clear, what are the key activities of each idea and who is responsible for what. Also, the value definitions of surface structure, lake liming and granulation will be explained and cost and revenue sources as well.

The selected ideas have several things in common that made them look more promising than other ideas suggested in the workshop. They are potentially large volume scenarios which was considered as a definite positive. SMA Mineral's processes create large amounts of quite heterogeneous side streams so the utilization idea should be something that isn't too affected by some variation. Therefore, especially reactive surface structure and lake liming are interesting possibilities. The selected ideas don't require too much pre-processing either which was noted by the workshop participants to be a big plus. Pre-processing quickly turns an idea unfeasible. The only pre-processing would probably be screening in certain cases. For example, a coarser fraction can be separated from fine calcite and used or sold as is.

3.3.1 Reactive surface structure

Extractive waste disposal sites and landfills require a surface structure when disposal site or disposal pile is not in use anymore. Government Decree on Landfills (331/2013) defines requirements for base structure and surface structure for landfill sites. These requirements are different for permanent, ordinary and hazardous waste. Requirements dictate, for example, different layers needed in the surface structure and how thick they must be. Extractive waste disposal sites don't have a set of standards in the legislation and they can be implemented in different ways. Each structure needs to be approved by the authorities and this plan is part of the environmental permit application.

Surface structure has many tasks. According to Finnish Environmental Centre's (2008) guide for landfill sites, surface structure prevents rain water from being absorbed by the waste. This reduces the amount of water filtering through the waste and carrying detrimental elements to surrounding water system and environment. Surface structure also reduces odour nuisances and dusting. (Finnish Environmental Centre 2008) It can also prevent acid drainage by preventing oxidization of the waste or neutralizing acid forming waste (Karjalainen 2016).

SMA Mineral's side streams can be used as construction material in surface structures for landfills that store acid forming wastes. This means for example mines that process sulphide minerals. Their tailings contain sulphides which can cause acid mine drainages if exposed to oxygen and water (Karjalainen 2016). SMA Mineral's side streams are alkaline and have good neutralization capacity. They can reduce acid mine drainage by preventing acid from forming in the first place and neutralizing formed acid.

The surface structure ecosystem, value chain and rough business model were described in the workshop. The business ecosystem and value chain are presented in figures 7 and 8.

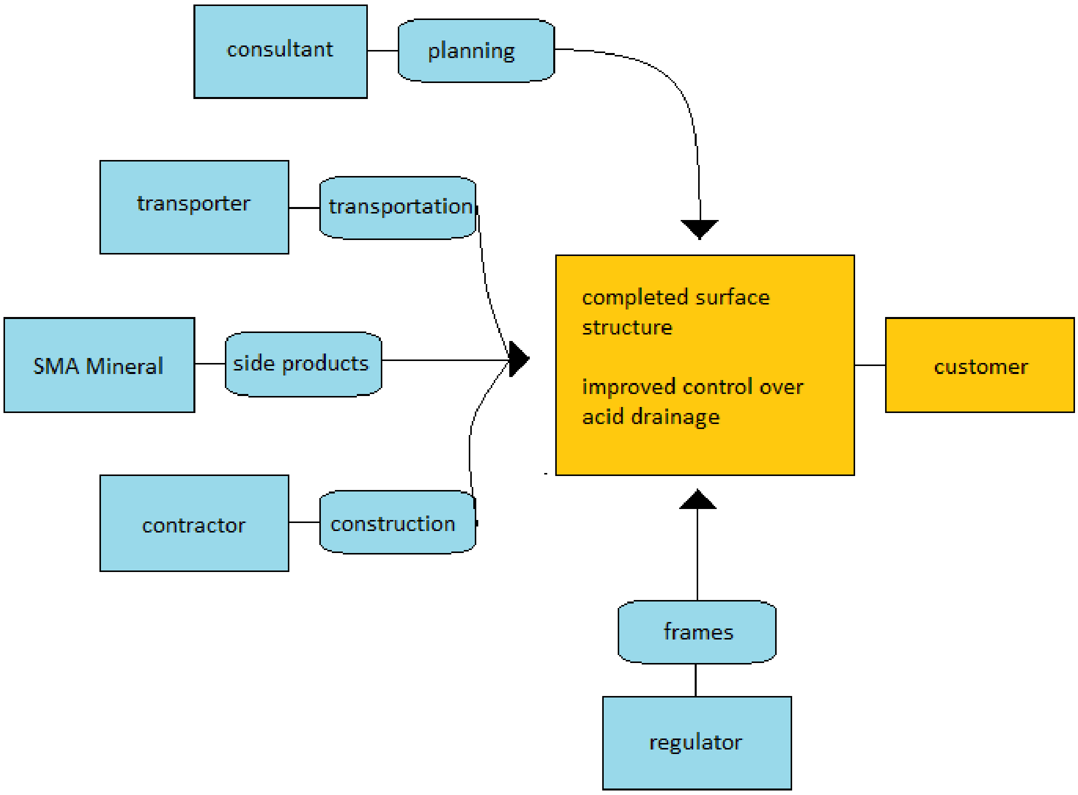

Figure 7. The business ecosystem of surface structure.

The ecosystem has six key members. Consultant does the initial planning of the surface structure which is needed for the environmental permit application. Regulator then reviews the application and decides if the plan is appropriate. If regulator approves the plan, it can be carried out. Constructor who is contracted to construct the surface structure then orders materials that are needed. SMA Mineral steps in at this point as it is providing its side products as construction material. Materials are given to transporter who delivers them to disposal site. Constructor can then build the surface structure according to the plan.

A rough business model was also sketched for surface structure in the workshop by defining value proposition, costs and revenues. Value proposition is improved control over acid drainage for the customer. It is easier to achieve set discharge limits and stay under them by using surface structure made at least partly from alkaline material. Costs come from the side products themselves. There is no need to pre-process side products. Revenue comes from selling the side products as construction material.

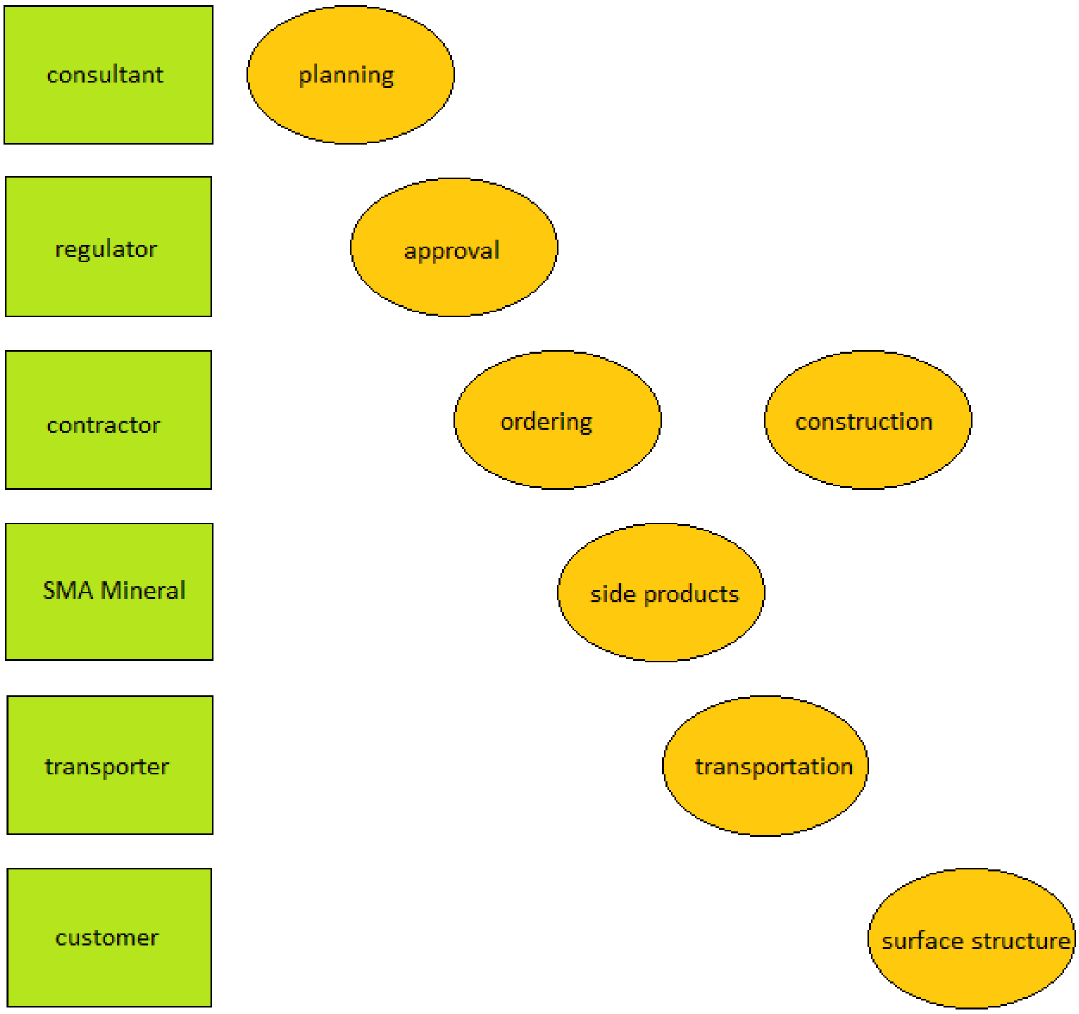

Figure 8. Swim lane chart of surface structure value chain.

3.3.2 Lake liming

The main goal of lake liming is preventing acidification and neutralize already acidic lakes and harmful effects that are caused by acidification. Acidification weakens the lake's ecosystem and its ecological functionality for example by lowering its biodiversity. Population in natural waters is accustomed to pH-range of 6.0 – 8.0 and they suffer in more acidic conditions which leads to decrease in fish populations and lack of biodiversity as species disappear from the water. (Weppling & Iivonen 2005, Oravainen 1999)

The most important causes for acidification in Finland have been air pollution, sulphate soils in coastal Finland and humus. Air pollution has been traditionally caused by the use of fossil fuels, which has released sulphur and nitrogen in the atmosphere. Sulphur and nitrogen emissions then cause acid rains and fallouts. Sulphate soil cause acidification when the sulphur compounds in the soil are exposed to oxygen and oxidized into sulphates which then react with water and form sulphur acid. Sulphur acid dissolves heavy metals from the soil and causes lowering of the pH and accumulation of harmful heavy metals in surrounding water system. Humus has a big effect on Finnish water systems one of which is acidification. Peat industry, agriculture and forestry are sources of humus waters. (Weppling & Iivonen 2005, Vertanen 2016, Kurri 2011)

SMA Mineral's side streams are alkaline and they have good neutralization potential. They do not contain harmful amounts of metals and they are not toxic. Side products could be used in projects to revive acidified lakes or to proactively protect lakes that might be sensitive to acidification. Lake liming's ecosystem, value chain and rough business model were described in the workshop. Figures 9 and 10 illustrate the business ecosystem and value chain of lake liming.

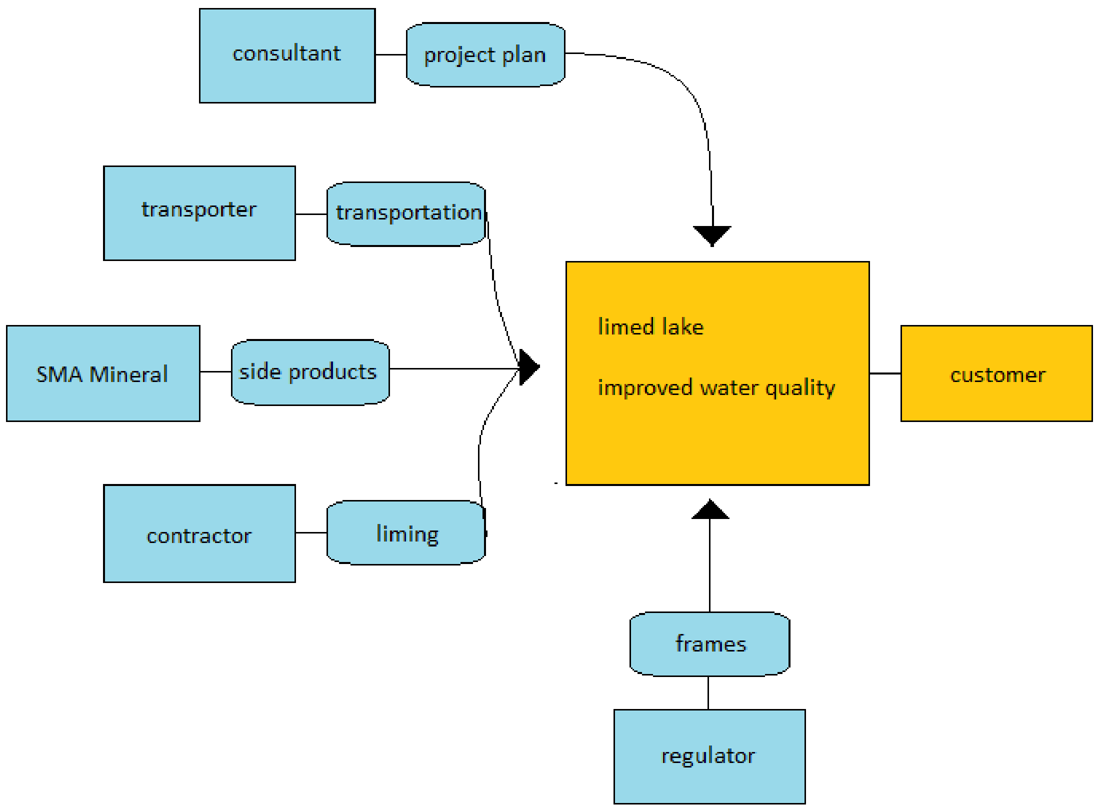

Figure 9. The business ecosystem of lake liming.

The lake liming ecosystem has six key stakeholders. Consultant is responsible for doing a liming plan for the project. Based on the plan, SMA Mineral provides required side products for liming. Transporter delivers them to the contractor who is responsible for the liming. After lime is spread into the lake, its pH will rise over time. Regulator provides legislation and guidance to the ecosystem.

Value proposition, costs and revenues were also defined for the business model. Liming improves water quality by neutralizing the water, this in turn improves the living conditions of the lake and will in time improve the diversity of its ecosystem. Costs are caused by the side products, screening and sacking. Revenue comes from selling the side streams as liming products and/or from possible public funding of liming projects.

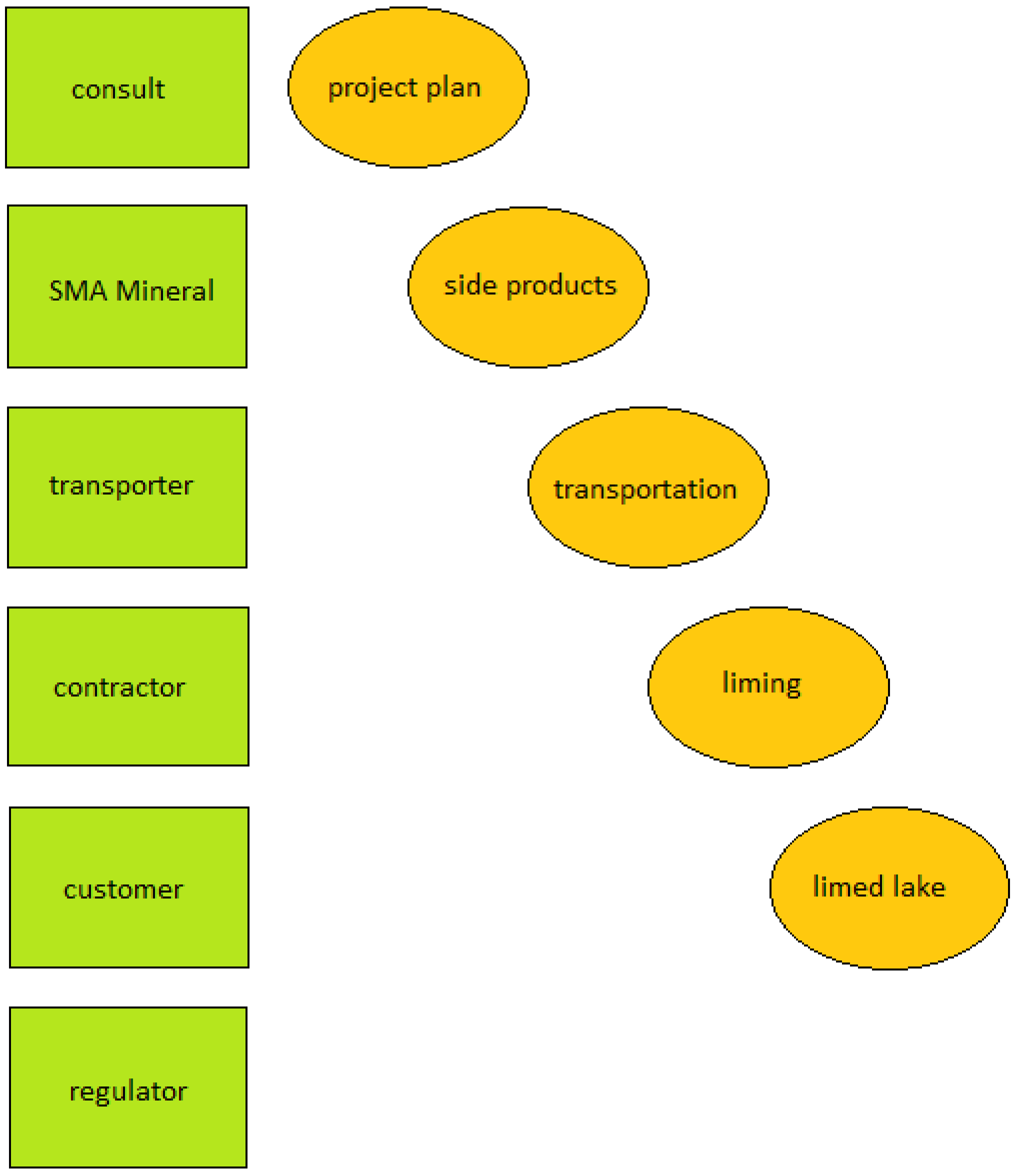

Figure 10. Swim lane chart of lake liming value chain.

3.3.3 Granulation/briquetting

Agglomeration means phenomenon in which particles are enlarged by sticking them to each other or to surfaces. Agglomeration process is used to prevent segregation, improve flow properties and bulk density for example. It allows control over particle-size distribution and reduce dustiness of the material. There are three kinds of agglomeration mechanisms: wet agglomeration, pressure and sintering. (Jenkins 2016) There are different kind of agglomeration processes such as briquetting, pelletizing and granulation.

It was noted in the workshop that this idea should be examined from two different angles. First, granulizing the side products for sale and see how that affects their value and second, agglomerating the fine calcite and possibly other side streams to make them suitable material for the lime kiln. There have been two agglomeration tests for fine calcite before the workshop. During the first set of tests, fine calcite, filter ash and burnt lime were granulated using different amounts of water and various recipes. These tests weren't a great success as the granules were fragile and not uniform. Second tests turned out quite well though. This time fine calcite, filter ash, burnt lime, cement and water were used in briquetting and resulting briquettes were sturdy and their mechanical strength was quite good. (Tecwill Granulators Oy 2015, Tecwill Granulators Oy 2016)

The granulation ecosystem, value chain and rough business model were described in the workshop. The business ecosystem and value chain are illustrated in figures 10 and 11.

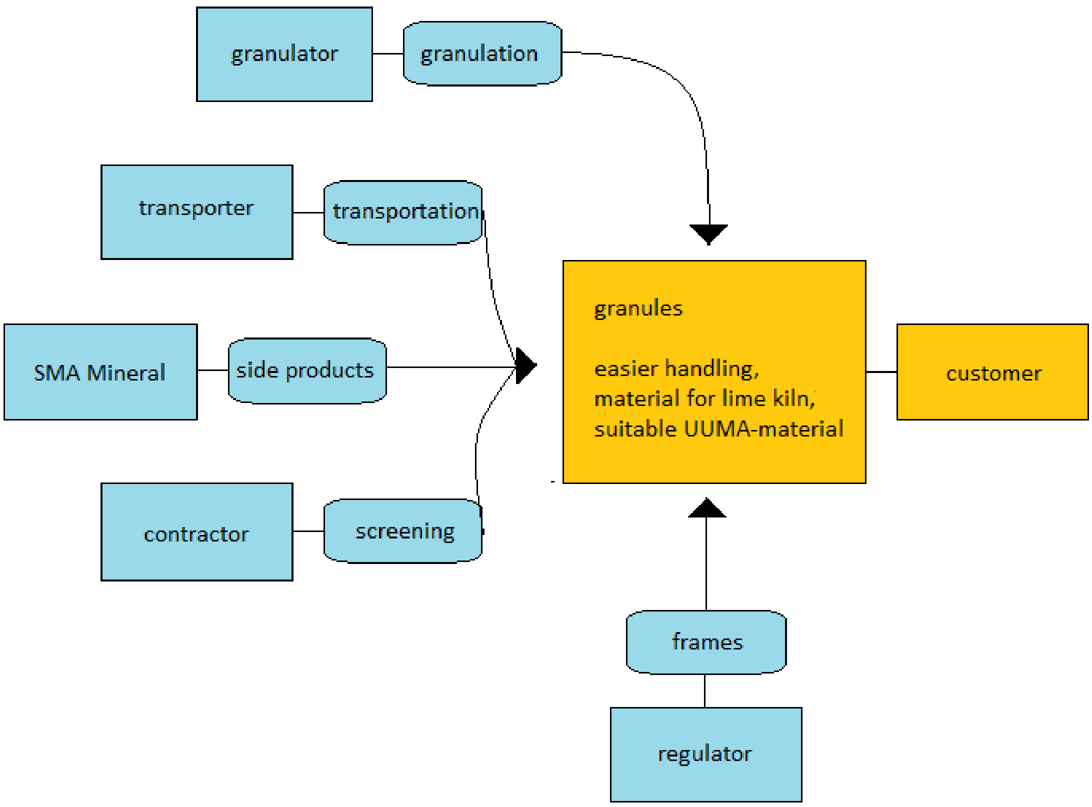

Figure 11. The granulation ecosystem.

There are six key stakeholders in the granulation ecosystem. SMA Mineral is the provider of material needed for the briquettes or granules. Some of the material might need screening to separate coarser fractions for other use. Granulation or briquetting is done by a contractor with mobile plant at the site. Transporter delivers agglomerated products to the customer.

It needs to be noted that this is the general picture for the ecosystem and it differs lightly for the two angles. Granulizing and selling side product granules would mean that there is a separate customer as a stakeholder and a key partner who is responsible for delivering side product granules to the customer. Side stream briquettes would be used by SMA Mineral themselves by burning them in the lime kiln and resulting CaO briquettes would be then sold. Because the assumption is that agglomeration is done in situ there wouldn't be need for transporting until deliver of briquettes.

Value proposition, costs and revenues were also described in the workshop. Because the customer segment for this end-use scenario can be split, there are more than one value proposition. One big advantage for the customer is the easier handling of granules. Granules don't generate dust unlike powdered products yet they still have quick effect on pH when liming the soil for example. Granules quickly disperse on the ground when exposed to water. For the briquette scenario value for the customer comes from suitable CaO product for applications that don't have very strict quality standards, and from the company's point of view naturally benefit is the ability to utilise large amounts of side streams for CaO production. Other value proposition that was thought of is the possibility to use side stream granules for earth construction as they are considered UUMA material (recycled material). Costs in this scenario come from the materials needed for the agglomeration process, agglomeration, coal gas (briquettes), screening and sacking. Revenue would come from selling the granules or briquettes.

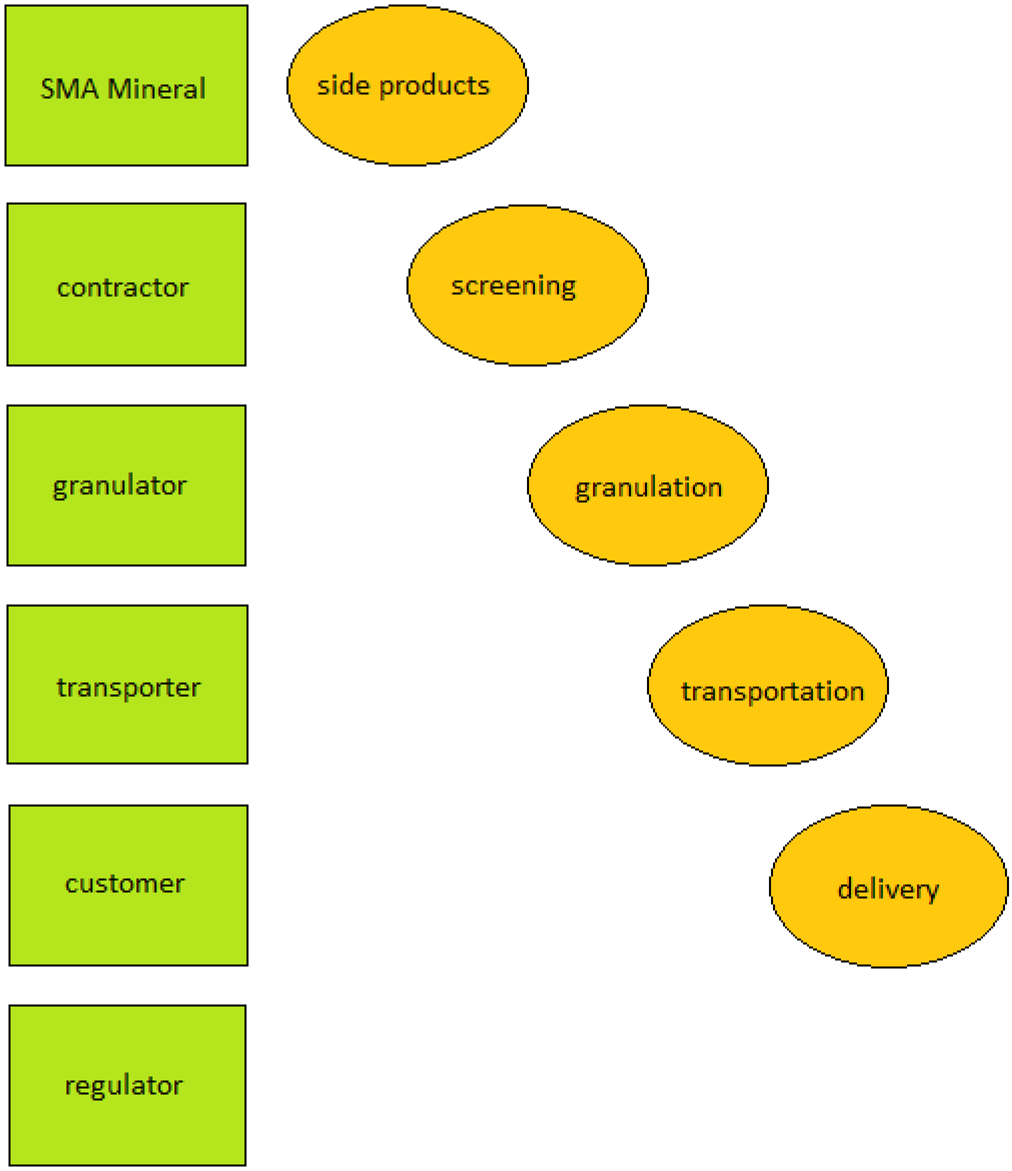

Figure 12. Swim lane chart of the granulation value chain.

3.4 Market assessment

3.4.1 Reactive surface structure

In the case of the surface structure scenario there are possible customers in mine industry who mine and process sulphide minerals. Their tailings will form sulphur acid and cause harmful acid mine drainage if not properly protected from oxidizing. Other possible customers are landfills with acid forming waste. Potential customers are currently active mines and landfills, future projects and already closed sites as well. It is possible that as the environmental laws tighten, and more attention is paid to reduce waste and emissions and their effect on environment, old disposal sites and tailings basins need to be upgraded to modern standards and this could open potential markets for reactive surface structure in that segment.

The main benefit of reactive surface structure is easier and more predictable control on acid drainage. A master thesis is under way on using SMA Mineral's side products as structure material and the preliminary results have been promising. More testing might be needed on long term effects and durability of neutralizing components. Using side streams as material also reduces the amount of virgin material needed. This might be a benefit in the future. Another possible benefit is cost reduction. According to Karjalainen (2016) closing a tailings basin can account for half of a mine's shutdown costs. Excavating and transporting virgin material can be costly and using inexpensive side products which are relatively close can offer cost reductions.

Competition in this market is quite severe. There are several different industrial side streams - such as fibre clay, ash and gypsum - researched as possible surface structure materials to reduce the use of virgin material, improve properties of aggregate materials and reduce closure costs. Moraine is currently the most used material and if it's readily available near the mine, it is tough to compete against it. For reference, in SMA Mineral's disposal site permit application the cost of moraine was estimated to be 5 €/m^3 (Ahma Ympäristö Oy 2015b). Other competitors are alternative methods to control acid drainage such as water treatments. The competition is most likely to increase in the future as there is more and more pressure to reduce the use of virgin materials, reduce costs and increase the utilisation of by-products.

3.4.2 Lake liming

In the lake liming scenario, the market is harder to define, because lake liming has been and still is quite rare in Finland. According to Weppling and Iivonen (2005) after 1975 approximately 200 lakes have been treated and in the early 2000s only a couple of lakes were limed yearly and based on the discussion in the workshop the situation has not really changed. However, there is some potential because there are lakes that would benefit from liming even though water conditions in Finland are quite good in general. Potential customers are mostly landowners such as the state and private parties, also possibly private entities like local fishery associations and such are possible customers. It is possible that growing environmental consciousness leads to policy changes in the future that would allow the state to support lake liming with funding which could boost the demand. Weppling and Iivonen (2005) notes that lake liming is supported in Norway and Sweden, latter of which has budgeted 200 million Swedish crowns yearly for lake liming projects and consequently, lake liming is a lot more common in Sweden than in Finland.

This idea’s potential benefits are straightforward. Lake liming improves water quality which affects positively on lake’s ecosystem. Appropriate pH-level ensures more diversified flora and fauna and improves the ecological functionality of the lake. Improving a lake’s overall condition can make it more attractive for recreational use for example. The positive effects must be guaranteed by water and side product analysis. Products used for liming need to be pure and not contaminated with harmful metals, for example. Using impure lime could weaken the situation by contaminating the lake with harmful substances. It is also important to conduct preliminary water analysis and make liming plan based on the results to ensure that appropriate amount of lime is used.

There is not that much competition in this market. Biggest competitors would probably be other members of lime industry. Biggest factor is the distance between lime and the target lake. If lime needs to be transported across the country it makes the project easily too expensive. Therefore, the target area for SMA Mineral’s side products would probably be lakes in the northern Finland. There is probably some indirect competition as well. Liming treats the symptoms, but it is possible to treat the cause, meaning that the source of acidification can be removed or nullify its impact so that liming isn’t needed.

3.4.3 Granulation

This market needs to be split and examined from two different scenarios as there are two different end-products. Side product granules can be sold for example to agriculture and earth construction. There is constant demand for products like these. Farmers need to maintain soil quality by liming every few years and earth construction projects can use UUMA materials to reduce the amount of virgin material needed. CaO briquettes could be sold to customers who need burnt lime but don’t necessarily need the best quality. Burnt lime is for example widely used in many industrial fields such paper and pulp, steel and mining for various purposes.

The benefits for the granules come from easier handling. Granulized products do not cause dusting problems like fine powders and they are easier to store, transport and spread. Granules are fast-acting when applied because they disperse quickly when exposed to water. CaO briquettes could be a product for customers who haven’t too strict requirements and from SMA’s point of view the clear benefit would be transforming otherwise useless material into a sellable product. Requirements for granules are that they need to be proven to have enough neutralizing capacity and to not include harmful substances. CaO briquettes need to have similar properties as burnt lime and they need to be suitable for lime kiln.

Granules would be competing against other lime products. SMA Mineral has other products for agriculture and side products would be competing against them partially. Burnt lime is one of the main products of SMA Mineral and naturally briquettes would be somewhat overlapping that market. However, briquettes could be considered and marketed as slightly cheaper secondary product for those who don’t need or cannot afford high-quality premium burnt lime. Also, there is quite a lot of potential market segments for calcium oxide products so overlapping might not be that big of a problem in the end. Distance between SMA Mineral and a customer is also a factor.

3.5 Technical feasibility

Some of the selected scenarios are already technically feasible and others need more research. Surface structure scenario has been researched and there has been a pilot test which is a subject of a master thesis as well. In the pilot six different demo structures are tested to see which kind of an effect they have on acid drainage. The zero option is only acid forming tailings, one of the structures is made of moraine which is the most common material used and rest are combination of SMA Mineral’s side streams and moraine in different amounts and compositions. In the workshop it was noted that the preliminary results have been promising and structures using side streams reduce acid drainage clearly. Long-term effects might need more research because it is possible that neutralizing material runs out over time.

Lake liming is already technically feasible with SMA Mineral's side streams. Liming has been done for a long time and even though it is rarer in Finland, there is lot of experience in Sweden and Norway. In fact, SMA Mineral has its own liming machinery in Sweden because it is so common there. Calcite, filter ash, partly burnt lime and dolomite are all alkaline and they have quite good neutralization capacity even though some of the fractions might be heterogeneous in their neutralization capacity. They should be suitable for liming without further testing. Some of the side stream material might need screening to separate the finest fractions because of dust problems and some fractions might have somewhat undesirable composition if they have been stored outdoors for a long time.

There is probably most uncertainty over technical feasibility of the granulation/briquetting scenario. The first granule test results weren't good. While the side streams were successfully granulized (fine calcite, filter ash) using calcium oxide as a binder, the granules were very fragile (Tecwill Granulators Oy 2015). More testing is needed to find an appropriate recipe for SMA's side streams so that granules are more durable. The main benefit of the granules is their easier handling due to lack of dusting, but the mechanical strength of the granules must be good, so they don't break when transported or stored. In the second test SMA's side streams were made into briquettes and this time results were very good. The briquettes were durable, but they must be stored in dry conditions, otherwise they become brittle (Tecwill Granulators Oy 2016). More testing can be done to optimize the recipe. However, the briquettes have not been burned so there is no knowledge how it affects them. Theoretically, they should be durable enough, but this needs to be thoroughly tested before actual CaO briquette production could take place. It is uncertain how a reliable test can be arranged as it is not possible to test them in the actual kiln.

The selected scenarios are possible without major investments apart from the granulation/briquetting scenario. The only must-have investment that was brought up in the workshop was storage facility that is needed for every scenario. Currently, there really isn’t proper storage facility for side streams, instead the material is stored in heaps outdoors. This affects negatively their quality as they are exposed to weather for long times. For example, in the granulation scenario the agglomerated products must be stored in dry conditions or they become brittle and powdery and cannot be sold or used.

In the granulation/briquetting scenario, a granulation plant is needed as well. A granulation plant would be around one million euros as an investment, but most likely the granulation or briquetting would be done by a contractor with a mobile plant at the production site. Thus, there would be no need to invest in own plant. Other possibly needed investment are a conveyor to transport briquettes into the kiln or the storage and some sort of sacking line.

3.6 Strategic fit

Strategic fit of the selected scenarios was also part of the workshop’s agenda. It is important to assess how well do the selected scenarios fit with the company strategy. New products made from the side streams shouldn’t be in direct competition with SMA’s main products. It is not desirable to have product cannibalization within company’s portfolio as it would not offer a new area of business for growth, instead products would fight for the same market segments. Another important aspect to consider is how well the new business propositions are aligned with the company’s strategy and goals. For example, if the company’s strategy is to focus on certain areas of business then new products should be in line with that. Timing is also an important factor. It needs to be considered if it’s good time to introduce certain products or make investments or if the company should wait before proceeding with a new business opportunity.

The selected ideas all suit quite well SMA’s strategic interests. In the surface structure scenario there would be no overlap and no competition against SMA Mineral’s other products at all. That field would offer a completely new area of business. The same goes for the lake liming scenario. SMA Mineral’s main products are sold for other markets and they would be not competing in the lake liming segment. As far as the product portfolio is considered both the surface structure and the lake liming scenarios are very good from SMA’s point of view. The agglomeration scenario is not as good a fit as the other two in that regard because granules would probably be sold to agriculture for the most part competing at least indirectly with SMA Mineral's other agricultural products and the CaO briquettes would need to be sold for same markets as the premium burnt lime.

According to the workshop discussions, environmental values are very important for SMA Mineral. The company's goal is to conduct business sustainably and without harming the environment. In that sense circular economy would fit well SMA's goals. Utilizing the side streams would boost the company's material efficiency considerably and offer new business and growth opportunities. Selected scenarios offer possibilities to turn formerly useless negative goods of SMA's production process into valuable products according to the principles of circular economy, keeping their value circulating instead of just disposing them.

The timing for this kind of projects would be good as well. The selected scenarios are currently not really done so it offers a chance for SMA Mineral to become a frontrunner. Lake liming might offer possible business opportunities if some policy changes takes place and public funding comes available for lake treatment. This probably requires active participation with different cooperation projects and lobbying and it would be a good time to start doing them because changes like these take time. In general, now is a good time to research how these side streams can be utilised because they cannot really be stored in temporary storage anymore, and a disposal site would need to be built if they cannot be used or sold.

3.7 Status quo and disposal site

Currently majority of SMA Mineral's side streams are not utilised. Some of the side streams fractions are used in Cresco products which are aimed for agriculture. Some of the side streams are sold as Kalkmix products. There has been interest to take some of the side streams for free or for negative price, meaning that SMA Mineral would have to pay for the customer.

The last resort is building a disposal site for the side streams. If there is not enough potential for utilizing side streams they must be landfilled because waste cannot be stored in the production sites permanently. SMA Mineral has planned for a disposal site complex that consists of two separate disposal sites. One of which is for permanent waste such as fine calcite and fine dolomite. The other one is for ordinary waste (or hazardous waste) such as filter ash and calcination waste. Part of the analysis is to estimate how much disposal costs can be saved if side streams can be utilised instead of landfilling them.

4 BUSINESS CASE ANALYSIS

The last chapter combined theoretical foundation with empiric research. Theory of business ecosystems, business models and value chains were used to describe potential utilisation scenarios for SMA Mineral's side streams. Financial analysis is also needed to estimate economic feasibility of each scenario. Chapter 4 answers the third research question of "What are the potential economic benefits of selected value chain scenarios" by presenting the business side of selected value chain scenarios.

4.1 Business case details

Because some of the scenarios are based on solutions that have not been done or not really currently done in Finland, there really isn't knowledge about selling price or the possible yearly volume. One of the question is how the side streams are valued as a raw material. Naturally part of the production costs has been sunk in side products. For example, raw limestone costs about 30 €/t and approximately 10 % of it is too fine for the lime kiln resulting in 40 000 tons of fine calcite a year. In principle that is 1.2 million € every year. Also, part of the fuel, electricity, labour, etc. used in the production of the main products is sunk in other side streams such as filter ash and calcination waste. So, there is value in the side streams because part of the costs has been caused by them. However, those costs belong really to the production of calcium oxide and dolomite products and cannot be used to value side streams. Let's use instead the selling prices for SMA Mineral's side streams found in Rapakko (2016) for estimations.

- fine calcite 2 – 5 €/t
- filter ash 4 – 7 €/t
- partly burnt lime/calcination waste 5 – 8 €/t
- mixture of filter ash and fine calcite 1 – 3 €/t
- fine dolomite 2 – 5 €/t (Rapakko (2016) did not have a price for dolomite, calcite is used for reference)

Another assumption is that transportation costs are paid by the customer. Distance is one of the most important factors of the feasibility. Because SMA's side streams are in Tornio area it means that the possible market is also in northern Finland for the most part. According to Rapakko (2016) 100 km of truck transportation costs 9 – 11 €/t and 350 km of transportation costs 20 – 24 €/t. Long distances drive up the costs and can turn otherwise promising scenario unfeasible in the end.

In the selected scenarios labour is needed for example to load and pack side streams and products, transporting, sales and marketing and operating a lime kiln. Workforce is also needed to operate granulation plant in the granulation scenario, to spread the lime in the liming scenario and to build the surface structure. It is assumed that these would be done by a contractor as was discussed in the workshop. It is hard to estimate how much labour is needed in each scenario outside the assumed contractor work at this point, so for simplicity sake they are left out in this thesis. This naturally makes the calculations a bit optimistic and further research is needed to gain accurate information of the labour costs.

In the lake liming scenario and granules scenario products are usually delivered in large sacks and a sacking plant would probably be needed. Based on quick online research cheaper end of 1000 kg sacks (flexible immediate bulk containers) cost approximately 5 €/sack and this is used to estimate sacking costs in the calculations. If higher quality containers or sack inner liners are required that would increase the cost.

For the overhead, let's use 10 % of variable costs. For these calculations, it is assumed that 40 000 tons of fine calcite, 5 000 tons of filter ash, 5 000 tons of partly burnt lime and 15 000 tons of fine dolomite is generated annually. To include an estimation of investments' impact on feasibility, 7-year linear payback is used.

One of the benefits of utilizing side streams is the cost savings from not disposing them. In this case, the disposing cost comes from transportation of the waste from production site to the disposal site. The disposal sites are at Kalkkimaa and Kvartsimaa. Filter ash and partly burnt lime from Röyttä will be transported to Kvartsimaa site and fine calcite from Röyttä to Kalkkimaa. Fine dolomite is produced in Kalkkimaa already and it does not need to be transported. The transportation cost for Röyttä – Kvartsimaa is 4.3 €/t and Röyttä – Kalkkimaa 3.6 €/t. Total disposing costs which include also the building costs are a bit higher, approximately 5.9 €/ton (see chapter 4.6). Because side streams are given a value instead of being free in the calculations, these costs would also apply to disposing but are left out for simplicity when comparing one scenario's feasibility to total disposing costs.

4.2 Reactive surface structure

In the surface structure scenario, SMA Mineral's side streams are sold as neutralizing construction material for reactive surface structures for acid-forming tailings basins and acid-forming waste disposal sites. Fine calcite, filter ash and partly burnt lime have been studied as reactive structure material and it is assumed that only they are utilised in this scenario. To estimate economic feasibility, let's assume that enough projects are found so that approximately a year's worth of side stream production is utilised. This way we can at least some way estimate the economic benefit.

Economic benefit of reactive surface structure

- variable costs 125 000 €/a
    - fine calcite 80 000 €/a (40 000 t, 2 €/t)
    - filter ash 20 000 €/a (5 000 t, 4 €/t)
    - partly burnt lime 25 000 €/t (5 000 t, 5 €/t)
- fixed costs 12 500 €/a
    - overhead costs 12 500 €/a (10 % of total variable costs)
- revenue 275 000 €/a
    - fine calcite 200 000 €/a (40 000 t, 5 €/t)
    - filter ash 35 000 €/a (5 000 t, 7 €/t)
    - partly burnt lime 40 000 €/a (5 000 t, 8 €/t)
- profit 137 500 €/a
- additional savings 187 000 €/a
    - fine calcite 144 000 €/a (40 000 t, 3.6 €/t)
    - filter ash 21 500 €/a (5 000 t, 4.3 €/t)
    - partly burnt lime 21 500 €/a (5 000 t, 4.3 €/t)

This very crude calculation shows that the profit potential of this scenario is 137 000 € and disposal savings 187 000 € if one-year output of side streams are utilised. Possible investment need for storage has a big effect on the feasibility of this scenario. For example, with 1 000 000 € investment using 7-year linear payback the scenario would be unprofitable by -5 000 €/a. However, if compared to the total disposing cost of 5.9 €/ton, surface scenario is very feasible when compared to landfilling.

One thing to consider is that dolomite waste is not utilised and it may need to be disposed if it cannot be used in surface structures or otherwise. Using the already existing heaps shouldn't be much of a problem as these projects require vast amounts of material. Tailings basins for example can be dozens of hectares, even hundreds, in area. If side streams are used only for a small reactive layer within the structure (0.3 m thick), a 50-hectare tailings basin would need 225 000 tons of material (assuming density of 1.5 t/m^3) for the reactive layer.

4.3 Lake liming

In the lake liming scenario, SMA Mineral's side stream are sold for improving water quality of lakes by increasing their pH and preventing acidification. Because lake liming is hardly done in Finland it is challenging to estimate the economic benefit of this idea but Sweden can be used as a reference to estimate the possibilities.

In Sweden, SMA Mineral's customers in the lake and wetland liming business are almost exclusively municipalities which finance their liming projects with tax funds and only a few private customers such as fishing associations every year. The total support of lake liming in Sweden is approximately 19 M€/year. SMA Mineral's yearly volume in lake liming is 45 000 – 50 000 tons and price range for liming products is 24 – 43 €/tons ex works. They offer Cresco products for lake and wetlands liming (Dos, GX, Sjö) which are made from milled and dry calcium carbonate (particle size under 1 – 2 mm).

To estimate the economic benefit, let's assume that it would be possible to achieve same level of lake liming in Finland as in Sweden. Considering that in Sweden only very fine products are used, let's only use side stream fractions of under 5 mm in the calculations as well. Approximately 30 % of fine calcite is under 5 mm in particle size and it is assumed that other side stream fractions are under 5 mm. Screened fine calcite is more valuable than non-screened and the additional value depends on the fraction size (larger is more valuable), for 0 – 5 mm fraction 7 €/t is used in this work.

Economic benefit of lake liming scenario

- variable costs 384 000 €/a
  - fine calcite 0 – 5 mm 84 000 €/a (12 000 t, 7 €/t)
  - filter ash 20 000 €/a (5 000 t, 4 €/t)
  - partly burnt lime 25 000 €/a (5 000 t, 5 €/t)
  - fine dolomite 30 000 €/a (15 000 t, 2 €/t)
  - screening 40 000 €/a (40 000 t, 1 €/t)
  - sacking 185 000 €/a (37 000 sacks, 5 €/sack)
- fixed costs 38 400 €/a
  - overhead costs 38 400 €/a (10 % of total variable costs)
- revenue 888 000 €/a
  - fine calcite 288 000 €/a (12 000 t, 24 €/t)
  - filter ash 120 000 €/a (5 000 t, 24 €/t)
  - partly burnt lime 120 000 €/a (5 000 t, 24 €/t)
  - fine dolomite 360 000 €/a (15 000 t, 24 €/t)
- profit 465 600 €/a
- disposal savings 86 200 €/a
  - fine calcite 43 200 €/a (12 000 t, 3.6 €/t)
  - filter ash 21 500 €/a (5 000 t, 4.3 €/t)
  - partly burnt lime 21 500 €/a (5 000 t, 4.3 €/t)

If lake liming was supported in Finland like it is in Sweden, then this scenario could offer promising profit potential. The calculation shows that yearly profit would be 465 000 € and additional disposal savings of 86 000 €/year. Using a very rough estimated investment of 1 M€ (for storage facilities, sacking line) the break-even point for this scenario is around 13 €/ton.

It is assumed that side products are managed to capture and storage dry, and this would probably require an investment to storage facilities. Because liming products are often delivered in large sacks, sacking plant would probably be needed as well. With an estimated investment of 1 M€ (7-year linear payback) the profit would still be over 300 000 €/year. Only finest fractions of SMA Mineral's side streams are assumed to be used for lake liming, but it could be possible to use the coarser fractions as well, but they would have a slower effect on the pH-level.

Lake liming is not currently supported with tax funds in Finland, so this calculation doesn't reflect the situation very well. Currently, it would probably be best to seek cooperation with universities and research institutes to arrange lake liming projects and apply for funding that way. The company usually has to partly fund the project and the funding can be monetary, work contribution, materials etc. These projects could then be used to demonstrate the positive environmental effects of lake liming and the need for liming support policies in Finland. Compared to landfilling, the liming projects would be feasible if total costs are under 5.9 €/ton.

4.4 CaO briquettes

In this scenario SMA Mineral's side streams are utilised by making briquettes and then using them as raw material for the lime kiln. The end product is CaO briquette that can be sold for various industries such as paper and pulp, steel and mining industries. According to briquetting tests that have been made, required materials are fine calcite, filter ash, binders and water. Binders in the recipe are burnt lime (CaO) and cement. Tests were carried out with regular tap water and carbonated water, latter giving harder and more durable briquettes. For simplicity, it is assumed that regular water is used in this analysis. A ton of burnt lime requires roughly two tons of lime stone and this rate is used for the briquettes as well.

SMA Mineral's selling price for burnt lime is 120 – 150 €/t (Rapakko 2016). Let's assume that the price for calcium oxide binder is 135 €/t. The cement grade that was used in the briquetting tests is available at resellers for approximately 270 €/t. Lime kiln uses coal gas as fuel and it costs 15 – 30 € for 1 ton of burned rock (Rapakko 2016) and 22.5 €/ton is used in this work. The briquetting cost would be around 6 €/t. As the production of calcium oxide releases carbon, emission allowances are needed, and they cost around 5 € per ton of calcium oxide (Rapakko 2016). Water costs 1.50 €/metric cube. For the selling price of CaO briquette, let's use 135 €/t.

Economic benefit of CaO briquettes

- variable costs 2 898 902 €/a
    - fine calcite 80 000 €/a (40 000 t, 2 €/t)
    - filter ash 23 128 €/a (5 782 t, 4 €/t)
    - burnt lime 637 200 €/a (4 720 t, 135 €/t)
    - cement 318 600 €/a (1 180 t, 270 €/t)
    - water 10 974 €/a (7 316 t/a, 1.5 €/t)
    - briquetting 354 000 € (59 000 t, 6 €/t)
    - emissions 147 500 € (29 500 t, 5 €/t)
    - coal gas 1 327 500 € (59 000 t, 22.5 €/t)
- fixed costs 289 890 €/a
    - overhead 289 890 €/a (10 % of total variable costs)
- revenue
    - CaO briquettes 3 982 500 €/a (29 500 t, 135 €/t)
- profit 793 708 €/a
- additional savings 168 863 €/a
    - fine calcite 144 000 €/a (40 000 t, 3.6 €/t)
    - filter ash 24 863 €/a (5 782 t, 4.3 €/t)

Total economic benefit of the briquettes scenario is 960 000 €/a. Profitability looks promising even when with an estimate for needed investments. For example, with overall investments of 1 million € and using 7-year linear payback, profit would still be 650 000 €/a, and with 2 million € investment briquette scenario would still be profitable by 507 000 €/a. In addition to that almost 170 000 € would be saved in disposal costs every year. The break-even point for this scenario is around 118 €/ton using an estimated investment of 2 M€.

Only filter ash and fine calcite are utilised in this scenario. Some other use would have to be found for partly burnt lime and fine dolomite or they would need to be disposed.

Perhaps it could be possible to fine tune the briquette recipe and include partly burnt lime or fine dolomite as ingredients.

4.5 Granules

In this scenario side streams are granulized and sold as special product for agriculture, other possible uses are in earth construction for example. This analysis focuses on the agriculture use. Granules are easier to handle, store and apply and these factors increases the value and because they are made from fine particles their effect on pH is quicker than coarser material's. To estimate possible value increase we can look at competing products in the market.

There are both very fine milled lime products (fraction size lower than 1 or 2 mm) and granulized products (particle size from mm to µm). These products are aimed at small scale users such as gardening enthusiasts and sold in small sacks (10 – 25 kg). Price range for fine material products are 260 – 320 €/1000kg and for granules 750 – 800 €/1000kg at resellers. Based on this quick research the value of granule products is over 2.5 times bigger than value of non-granulized products.

For professional agricultural and larger scale use, bulk liming products are priced in the range of 15 – 30 €/ton (Kalkkitaulukko 2016). These are usually calcite or dolomite lime with particle size smaller than 2 – 8 mm. One competitor offers also a granulized (granule size 1 – 4 mm) calcite marketed as a special product for precise treatment of problematic spots of the soil and for treating yards and gardens. It's advertised as fast-acting and easy to handle and apply. This product is considerably more expensive than general liming products with price of 130€/500kg. There is also another granulized calcite product (granule size 2 – 6 mm) for quick boosting pH in problematic soil spots that is sold in 600 kg sacks. It costs approximately 215 €/ton at reseller.

As mentioned before, the first granulation tests were not a great success. Even though it was possible to granulize the side streams, the granules were fragile and would break easily especially if exposed to moisture conditions. The recipe requires a lot of work and testing, but for these calculations one of the tested recipes is used. Granulizing cost is 6 €/ton, water cost 1.5 €/1000l and screening cost is 1 €/ton. Burnt lime is used as a binder and it costs 135 €/ton. Let’s use the retail prices of competing granule products for reference and assume that producer’s cut is approximately half. This way we get an estimated selling price of 107 – 130 €/ton (24 % value added tax included) for the reference granules and 86 – 104 €/ton without the tax.

Approximately 30 % of fine calcite is under 5 mm in particle size. It is probably not sensible to granulize larger fractions because they don’t dust as much and not much benefits would be gained from granulizing. This means 12 000 tons/year of fine calcite material for granulation. Based on that amount and the recipe used, 16 000 tons of granulized product would be possible yearly output.

Economic benefit of granules scenario

- variable costs 403 312 €/a
    - fine calcite 0 – 5 mm 79 856 €/a (11 408 t, 7.00 €/t)
    - filter ash 5 248 €/a (1 312 t, 4.00 €/t)
    - burnt lime 179 280 €/a (1 328 t, 135 €/t)
    - water 2 928 €/a (1 952 t, 1.5 €/t)
    - granulation 96 000 €/a (16 000 t, 6 €/t)
    - screening 40 000 €/a (40 000 t, 1 €/t)
    - sacking 80 000 €/a (16 000 sacks, 5 €/sack)
- fixed costs 48 331 €/a
    - overhead 48 331 €/a (10 % of total variable costs)
- revenue
    - granules 1 440 000 €/a (16 000 t, 90 €/t)
- profit 908 357 €/a
- additional savings 46 710 €/a
    - fine calcite 0 – 5 mm 41 069 €/a (11 408 t, 3.6 €/t)
    - filter ash 5 642 €/a (1 312 t, 4.3 €/t)

Combining profit and disposal savings gives the total economic benefit of 950 000 €/year. This scenario requires investments such as storage space, sacking line and granulation plant. With estimated investment of 2 M€ and using 7-year linear payback, the profit is still 620 000 €/year. The break-even point for this scenario is approximately 52 €/ton using an estimated investment of 2 M€.

Granulized side streams could be marketed as special products for treating relatively small problematic patches of soil and for yard and gardening in smaller packages the same way as competitors are. This way granules would have their own market segment and would not be in direct competition with SMA Mineral's other agricultural products.

This calculation assumes that everything is sold, and this is not certain. A thorough market research would probably be required to find out the market potential. The granule products used for reference are made in Poland and Germany from chalk stone. There could be competitive advantage in being a domestic product in this segment.

In the calculation only screened very fine calcite and filter ash is used, but it could be possible to test and develop recipes for other side streams as well. Possible compositions could be for example fine calcite and fine dolomite, fine dolomite and filter ash.

4.6 Disposal

If side streams cannot be utilised, they need to be disposed. SMA Mineral has a preliminary plan for a landfill investment. Two separate sites would be built for disposing side streams. One site would be built at Kalkkimaa for fine calcite and dolomite. Kvartsimaa would be the location of the other site and filter ash, calcination waste and mixture of ash and calcite would be disposed there.

350 000 tons of waste could be disposed at Kalkkimaa in total. There is already 60 000 tons of calcite and 30 000 tons dolomite waiting for disposal and that leaves 260 000 tons of free capacity. With accumulation rates of 35 000 tons of calcite and 15 000 tons of dolomite a year the site would be filled in 5 years. Kvartsimaa has capacity of 157 000 tons of waste. Current storages are 30 000 tons of calcination waste and 60 000 tons of mixture. That leaves 67 000 tons of capacity left and with accumulation rates of 2 700 tons of calcination waste and 5 000 tons of filter ash it would take less than 9 years to fill it.

Rough estimate for the building costs of the disposal sites is 1 M€. Base structures would cost approximately 500 000 € and surface structures another 500 000 €. Consulting and permit process would cost around 50 000 €. In total investment for building the landfill would be 1.05 M€ approximately. However, if one of the sites is for hazardous waste it would most likely increase the costs.

Since the side streams are not subject to waste tax only cost is the transportation to the site. Disposal costs to Kalkkimaa site are approximately 3.6 €/t, total 350 000 tons would cost 1.26 M€. Disposal costs to Kvartsimaa site are approximately 4.3 €/t, total 157 000 tons would cost 675 000 €. The total costs of building and filling the site would be almost 3 M€ (approximately 5.9 €/ton).

A security deposit is also needed according to Finnish legislation (190/2013, 527/2014). Deposit should cover estimated waste management costs and closing and monitoring costs (Finnish Environmental Centre 2012). Because only permanent waste would be disposed at Kalkkimaa site, no deposit is required for that site (Ahma Ympäristö Oy 2015b). Deposit for ordinary waste disposal site was suggested to be 89 000 € in the environmental permit application. Finnish Environmental Centre's (2012) Waste Security Deposit Guide states that suggestive deposit based on area for hazardous extractive waste is 5 – 7 €/m^2. The Kvartsimaa site is 1.72 hectares. Suggestive deposit would therefore be at least 86 000 – 120 000 € if filter ash and calcination waste are considered as hazardous waste.

Although SMA Mineral's side streams are currently not waste taxable, this could possibly change in the future as environmental legislation gets stricter and linear model of modern economy is replaced by principles of circular economy. This would significantly increase the costs of disposing and make utilising side streams a must in practice. For example, with current waste tax rate of 70 €/ton. This would drastically improve feasibility of many utilisation scenarios as the total disposing costs would rise to 75.9 €/ton.

4.7 Status quo

Currently side products of burnt lime production and dolomite processing are not used for the most part, instead several tons are accumulated every year and stored at the production sites. There are at least 60 000 tons of fine calcite and another 60 000 tons of calcite-ash mixture at Röyttä and 30 000 tons of dolomite waste and another 30 000 tons of calcination waste at Kalkkimaa. Yearly addition is 6 – 35 000 tons of fine calcite, 2 500 – 5000 tons of filter ash, 700 – 2 700 tons of calcination waste and 0 – 5 000 tons of dolomite depending on utilisation rate.

Part of the side streams are used to produce Cresco products which are SMA Mineral's main products for agricultural uses. A small portion of the generated fine calcite is dry and that can be utilised fully already. It can be sold for example as cattle feed lime and for power plants. Side streams are also sold as cheap Kalkmix products. In addition to current utilisation solutions, it has also been discussed if side streams could be given away for free or that customer could be even be paid to take them. It is estimated that with negative pricing, the cost would be several euros per ton. For example, partly burnt lime and filter ash have generated interest for this kind of arrangement.

It is not very efficient or sensible to sell cheaper side streams in the same markets as Cresco products so it should be made sure that Kalkmix products are sold for other uses than agricultural so that the risk of product cannibalization is minimized. For example, every ton of fine calcite that is sold for agricultural user can be in principle thought of as a loss of sale of Cresco product. Giving away or paying for a customer to take side streams is also not ideal, as there is potential for new business in side streams with some research and investments. There is also a related risk for negatively affecting sales of other products. For example, would sale of Cresco products suffer if fine calcite were given away for free or how would market situation change if a customer is paid to take side streams and its business is in competition with SMA Mineral's other products. This risk should probably be assessed case by case. However, if the cost for getting rid of the side streams is lower than 5.9 €/ton it should probably be at least considered.

4.8 Recommendation

Based on the economic analysis there is potential for new business in SMA Mineral's side streams and continuing to research and explore their utilisation is probably the right way to go. The analysis showed that there is most economic benefit in the granulation scenario, both briquettes and granules. However, they are also the options with most uncertainty. They both require lot of additional research to become technically feasible and there is also uncertainty regarding the actual demand, selling prices, etc. These uncertain factors can affect greatly the possible profitability. The reactive surface structure and lake liming scenarios are technically more feasible, but their potential economic benefit does not look as promising. The results are synthesized in figures 13 and 14.

	Economic feasibility	Technical feasibility
surface structure	Moraine is cheap and readily available, large transportation costs, lots of potential competition	Tested side streams reduce acid drainage, long-term impacts might need further research
lake liming	No customers without public funding and no radical changes in the horizon	Side streams have good neutralization capacity, they don't contain harmful amounts of metals or other toxins
CaO briquettes	Financial analysis showed that briquettes could be profitable even with some investments	Lot of further research needed to determine composition, suitability for lime kiln and quality
granules	"Special agriculture granules" had promising profit potential with used preconditions	Additional research needed to find recipes, determine quality, actual demand & price, other uses
disposal	Construction, transportation, maintaining and supervising causes costs.	Preliminary plan already exists. Some uncertainty whether some by-products are considered hazardous

Figure 13. Economic and technical feasibility of value chain scenarios.

From purely financial point of view the most interesting option would probably be co-production of briquettes and granules. Using the finest fractions of calcite and dolomite waste to produce granules for agricultural use (and possibly other uses as well) and the coarser fractions for production of CaO briquettes could be a way to extract a lot of value out of SMA Mineral's side streams. This would also give a nice synergy in production and utilise every side stream fraction efficiently. The analysis showed that both scenarios could be profitable, but more research is needed and these options are probably long-term projects.

Competing granule products used for price reference in this work are made from very fine grounded chalkstone and it would probably be not possible to achieve the same level of quality with SMA's side streams which would naturally be reflected in the price level accordingly. Granules could still be branded the same way as a relatively fast-acting special product which is easy to handle and apply. They could be targeted especially for precise treatments, yards and gardening and be sold both in larger sacks and smaller "consumer size" sacks. Research is needed to find appropriate recipes for the granules, to test and verify their quality (neutralisation capacity, fast-acting % etc.) and to recognize full market potential (including other possible markets and uses than agricultural granules). Investments are also needed. A dry storage is required because granules break if they are exposed to humidity and if side streams are stored in the open it will affect their quality. Sacking line would probably be also needed. Granulation plant is a must, but a mobile plant could probably be contracted from a third party if there is no desire to invest in one.

SMA Mineral's burnt lime is sold for 120 – 150 €/ton and if CaO briquettes can be sold for nearly as much they would be a promising option for utilisation. Majority of generated side streams are too coarse for special granules, considering that the finer the material the faster its effects and more benefit in reduced dusting and easier handling is gained. Briquettes would be a good way to utilise the calcite that is too coarse for granules and too fine for lime kiln. Further research is needed to fine tune the briquette recipe to optimize the mechanical properties, to test whether the briquettes can be burnt or not and are they viable material for the lime kiln at Röyttä and if CaO briquettes' properties and quality are high enough that they can be sold. Investments that are needed are at least a storage investment, possibly conveyor and modifications for the process. Also a briquetting plant is needed, but it could probably be contracted.

Currently, the most realistic solution is probably the reactive surface structure. The preliminary results of a pilot project have been promising, showing reduction in acid drainage when compared to a moraine structure as was noted in the workshop. Surface structures requires enormous amounts of material and if SMA Mineral's alkaline side streams are used even for a relatively thin reactive layer within the structure, huge amounts of material would be needed. The profitability of this scenario does not look that promising as the selling price would probably have to be quite low as moraine is cheap and readily available. For reference 5 €/m^3 is used in SMA Mineral own disposal site plan (Ahma Ympäristö Oy 2015b). Transportation costs put also pressure on the price level as transportation can account for large share of the total shutdown costs. However, comparing to the total disposing costs of 5.9 €/ton if a disposal site were built, it would still be beneficial to sell materials cheaply, give them for free or even pay a little (part of the transporting costs for example) if costs per ton of side stream used remain under 5.9 €.

The lake liming scenario could be profitable if public funds were used to finance liming projects like in Sweden where the yearly support is around 19 M€. However, as this is not the case there really is no market for lake liming apart from occasional one-off projects. An interesting possibility could be some sort of cooperation projects with universities and research institutes to study effects of lake liming on biodiversity of environmental ecosystems and use those results to demonstrate the positive impacts lake liming has and the need for supporting it financially. Lake liming projects would be recommendable over a disposal site if the costs are less than 5.9 €/ton. It needs to be noted though that in general the condition of Finnish natural waters is already quite good (Ympäristöhallinnon yhteinen verkkopalvelu 2018). In the future the average conditions are probably not going to deteriorate because a lot of attention is nowadays paid to emissions and waste management.

	Future outlooks	Strategic fit
surface structure	It's probable that environmental laws get stricter and that could mean reducing the use of virgin materials	Does not compete with other products, a single project requires large amounts of material
lake liming	Finnish natural waters are in good condition in general, unlikely to deteriorate, policy changes uncertain	Not in competition with other products, straightforward and most of the side streams could be used as is
CaO briquettes	CaO widely used in many industries, unlikely to change, it's possible that emission allowance cost rises	Side streams converted into high value product, but it would compete against the main product
granules	Lime products used in many fields, unlikely to change, possible that there is pressure to reduce use of virgin material	Granules might be valuable products, but they would cause competition within product portfolio
disposal	It is possible that side streams would be subject to waste tax in the future	High material efficiency and environmental friendliness are company goals

Figure 14. Future outlooks and strategic fit of value chain scenarios.

In short term, it probably would be best to search projects such as reactive surface structure or lake liming to utilise side streams. They can be carried out without further research and the profit is not really that relevant because they are in principle feasible compared to a disposal site if the cost to SMA Mineral stays under 5.9 €/ton. However, when giving away side streams for free or paying for customer some sort of risk assessment should probably be done to ensure that it doesn't affect negatively other products of the company. In long term, it would probably be wise to further research the granulation and briquettes scenario as the analysis showed that they could potentially be profitable new business. Depending on the time span, if no reasonable utilisation projects can be found, it would be best to build a disposal site as a last resort because side streams and wastes cannot be stored at the production sites indefinitely. This would be in line with the 5-step approach for reducing waste as suggested by the Waste Framework Directive.

5 CONCLUSIONS

This chapter focuses on the work itself. It evaluates the contributions of the thesis and evaluates its validity and reliability. Themes and directions for further research are discussed as well.

5.1 Contribution

The main goals of this thesis are exploring limestone side stream utilisation and recognize possible value scenarios for SMA Mineral's by-products and analyse their economic feasibility. These goals were met by answering the research questions of this thesis.

The first research question was "How to analyse economic feasibility of industrial side stream utilization?" and it was answered by a thorough literature review. Based on the literature review it was recognized that a utilisation scenario needs to be described in three levels before the feasibility analysis. The first level is the business ecosystems, term coined by Moore (1993), which presents the big picture of the scenario, describing interlinked companies of the ecosystem that work to fulfil a joint value proposition. The second level is the business model which tells how a company in the ecosystem creates and captures value. Third level is the value chain, which is built around value proposition and consists of key activities required to complete it. These three levels are combined with the context to write a business case which can be analysed to gain objective information on economic feasibility of the selected scenarios.

The second research question was "What are the value chain scenarios for limestone processing side streams?" and it was answered in the empiric part of the work. The empiric research was done in workshops and interviews, using additional online research as a supplementary tool. Participants of the workshop were experts of the limestone industry and based on their expert knowledge value chain scenarios were selected. Part of the empiric part was also connecting the scenarios with the theory by describing them using the three-level approach recognized in the literature review.

The third research question was “What is the potential economic benefit of value chain scenarios?” and it was answered by doing a business case analysis. Business case combines theoretical knowledge and empiric research with the case and scenario specific context. Analysing the business case gives relevant information of the profitability and economic benefit of each scenario.

The results of this thesis are three different value chain scenarios for SMA Mineral’s side streams. These scenarios are described using the three-level approach identified in the literature review. The key members are identified, and it shows what kind of ecosystems needs to be formed in the scenario. Business models are roughly sketched to recognize costs and revenues which are needed for the economic feasibility analysis. The value chain’s key activities are presented and attributed to responsible members to illustrate dependencies and responsibilities in each ecosystem. The analysis show that the scenarios can be split in two. Reactive surface structure and lake liming scenarios have probably small economic benefit, but they are technically very feasible. The granulation scenario shows promising potential in its both variations (briquettes and granules), but its technical feasibility is uncertain and they require more research. Like Roos (2014) noted it is challenging to utilise side streams and create business around them because there are several different by-products and they cannot always be utilised in one scenario as was evident in the selected scenarios. This can be overcome by combining scenarios and utilising side streams in several ways so that there are no left-over fractions but everything is used efficiently instead.

5.2 Evaluation

This research is evaluated by examining its validity and reliability. Validity means how well the chosen research methods measure what they are intended to measure and how well the study itself answers the research question. Reliability reflects how easy it is to recreate the study. A reliable study can be repeated by using same data collection techniques and research methods and they yield similar results. (Saunders *et al.* 2016)

Qualitative and descriptive methods were used to gather data in the empiric part of this thesis for the most part. These methods were an innovation workshop and interviews. The chosen approach was very useful in this thesis because there wasn’t a real hypothesis for the work, but the goal was to explore the potential uses for the side streams in general. This relied heavily on expert knowledge of SMA Mineral's work force and that was harnessed in workshop and the interviews. The expert knowledge was essential to provide insight on which kind of scenarios are sensible, what are their strengths and weaknesses, what kind of ideas should be dropped, which factors make a scenario interesting and which don't. Description of the scenarios was also reliant on expert insights into key partners and key activities. Such information cannot really be gathered via quantitative methods. Interviews were part of this approach to use experts' knowledge and experience. More informal discussions were held with some researchers before the workshop when there wasn't a clear picture of the situation. Afterwards, when scenarios were selected, predetermined and precise questions were used to gain information on subjects which required additional information.

The descriptive methods were needed to develop potential scenarios and describe them, but this thesis would not have been a complete work without a financial analysis. Relevant business detail estimations were needed for the calculations and required data was gained by researching factors such as market prices, possible volumes and material prices. Some of the details were gained via the workshop and the interviews so those methods had a useful role in this part of the work as well. The analysis of economic benefit in this work was not meant to be an exhaustive analysis which can be used for business decisions but a preliminary work to suggest which steps should be taken next in SMA Mineral's goal of improving material efficiency. In that regard, rough financial analysis served its role well in gauging potential economic benefits of each scenario.

The methods used in this thesis were various and they complimented each other very well. The subject of this thesis relied heavily on expert knowledge and appropriate methods were used to exploit that expert know-how. The calculations are suggestive, based on assumptions and estimations that cause uncertainty but considering the nature and goal of this thesis, they serve their purpose. While more precise data is surely available for the calculations, it should be part of possible further research when an exhaustive business analysis is done.

The selected scenarios have a big impact on the outcome of the thesis. As was noted in the workshop, a lot of the possible scenarios might have seemed promising on the surface but with expert knowledge it was easy to point out several negative aspects that made some scenarios unfeasible. Without carefully planned workshop it would have been easy to end up with unattractive scenarios that would be without potential and the results of this thesis could have been different. It is also worth to point out that the context of this thesis is very specific and because of the side streams available and the location of the operations some scenarios were severely handicapped. In different context, for example, for a limestone producer in the southern Finland, the promising scenarios might be different.

In general level the methods used in this research should be applicable in other industries as well. Three level approach gives clear enough picture on the situation and can be used to develop an idea into a scenario which can then be analysed. Specific expert knowledge of subject field is essential for a successful study because without it it's practically impossible to ensure that all relevant possibilities are included and that the selected scenarios are worth looking into. That kind of work requires extensive knowledge of the side streams, company goals, industry in general etc.

The calculations are only rough estimates using educated guesses based on research and expert knowledge. While the results would most likely vary if other researchers did a similar study, the general picture should stay the same. Potential scenarios would still be potential and those not shouldn't become lucrative suddenly. An extensive and exhaustive business study of specific scenario would yield more accurate information and even then, there would be at least some uncertainty. Careful market research, investment calculations and exhaustive feasibility analysis are needed for final decisions, but those are areas that should be covered in further research. It is also important to note that the calculations are subject to time, and the results might be completely different in the future as there are many factors that can change. For example, environmental legislation might go through changes that have major impacts on these scenarios or on the industry in general.

5.3 Further research

There are several interesting directions for further research. In the granulation/briquetting scenario, additional research is needed to find optimal compositions for briquettes and granules. Study is needed to test whether the briquettes can be burned and what kind of properties the burned briquettes have. Granule testing is needed to find compositions that are durable and to verify their properties and possible uses (other than agricultural as well). Another possible theme for further research could be industrial side streams and their use in natural water treatments and how they affect ecosystem. More research can be done to find possible synergies with other industries and their side streams. One theme for further research could be an exhaustive analysis of a certain scenario as a next step to gain more accurate information on economic feasibility and risks like noted by Smith (2013) and Adner (2006) as those weren't really considered in this work.

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